

# **MANAGING DISRUPTIONS IN A REFINERY SUPPLY CHAIN USING AGENT-BASED TECHNIQUE**

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## SUMMARY

With growing competition in the economy and concomitant business trends such as globalization, single sourcing, outsourcing, and centralized distribution, supply chain networks are increasingly becoming more complex. Intricate, long and poor-visibility supply chains are vulnerable to disruptions, which can occur due to natural disasters, industrial disputes, terrorism, etc. Disruptions can have significant impact on the economics and the operability of any company, therefore timely and adequate response is essential for supply chain resilience. This is a complex problem where the suddenness of changes, short response times and resource constraints limit the flexibility in integrated decision-making. In this work, we present a structured model-based framework and a generic decision support approach for managing abnormal situations in supply chains.

The proposed approach involves an agent-based disruption management system and a separate supply chain simulation. The main challenges in disruption management are disruption detection, their diagnosis, seeking rectifications, optimization of rectification options and implementation of corrective actions. Our disruption management methodology therefore deals separately with all these steps of disruption management.

In this work, we present a framework which can help in making decisions while managing disruptions in a supply chain. The framework assimilates three basis parts namely: the real supply chain, a supply chain simulator and the disruption management system. We use a previously developed system called PRISMS (Petroleum Refinery Integrated Modeler and Simulator) to model the supply chain and develop a new system called Disruption Management System (DMS) to manage disruptions.

This framework is implemented for a refinery supply chain. PRISMS is a multi-agent system, in which each entity in refinery supply chain acts as an autonomous agent. The disruptions management system (DMS) is also implemented using a similar agent-based technique. The DMS represents a different department in a refinery which deals with disruption management. Different agents in the DMS perform different activities as per proposed framework. DMS has been implemented in an Agent Developed Environment using G2, the expert system shell.

Various case studies have been performed to evaluate different types of disruption management strategies. It is seen that continuous monitoring of supply chain is necessary; and it is also necessary that the refinery supply chain itself is proactive towards handling deviations. The direction of information flow has a critical impact on disruption management. Feedforward and feedback control methods have been evaluated and case studies show that both control methods are important for handling disruptions in a supply chain.

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## **Chapter 1 Introduction**

Supply chain disruption is a massive reduction in manufacturing or supply, resulting in stoppage or slowdown of downstream production. In a broader context, it is defined as losing the ability to deliver the right quantity of products at the right place and at the right time, while meeting the standard specification and level of cost efficiency.

The intense competition among companies is forcing the management to implement new strategies at the levels of both strategic planning and daily operations. As a result, supply chain is getting more complex and eventually losing its visibility from one end to another. Disruptions are also becoming common, as supply chain becomes incomprehensible and lengthy. Several recent incidents have shown that natural disasters, industrial disputes, and terrorism can be a serious threat to supply chains and result in disruption or blockage in its proper functioning. Similarly, the evolution of new technologies may also affect the demand, resulting in abnormal fluctuations in supply chain.

Consider an example of the fuel shortage at the Sydney airport (BBC News (2003) and Macfarlane (2003)) in September 2003, which clearly demonstrates the issue of supply chain disruptions and their effects. The average demand of jet fuel at the Sydney airport is 5-6 million liters per day, which is 40 percent of Australia's total jet fuel demand. Jet fuel is stored and distributed at the Sydney airport by an authority named Joint User Hydrant Installation (JUHI). Caltex, Shell, BP, and Exxon Mobil supply jet fuel to JUHI. Caltex supplies approximately 3 million liters and Shell supplies 2.6 million liters during a normal day to the Sydney airport. However, on 25 September 2003, the airport received only 1.4 million liters of Jet fuel. This resulted in cancellations and

diversions, rerouting of flights, disruptions to travelers, etc. The supply had started to decline on 15 September 2003, and by the 26<sup>th</sup>, it was disrupted completely and could not return to normal until 13 October 2003. The total financial impact was around 5 million Australian dollars. The root cause of the inadequate fuel supply was the production problems at the Caltex and Shell refineries in Sydney. The problem worsened, when a batch of fuel from Shell failed to meet specifications and was not accepted. Additional shipment, which was ordered from Singapore as a move to manage the situation, took time to reach the required place. The incident report identified the main reasons for the disruption to be lack of transparency between JUHI and the suppliers and poor contingency planning by JUHI. This research work focuses on the methodologies to monitor KPIs in supply chains, and also suggests framework for dealing with various disruptions in supply chain. Implementation of this methodology can help supply chain managers to effectively deal with incidents like Sydney Airport.

Disruptions in a supply chain can affect downstream operations, impact product quality, lead to shut down, cause start-up problems, delay product deliveries, etc. The linkages of supply chain and effects of one entity's function on another's are illustrated in Figure 1.1. Often, disruptions go unnoticed and are inherently ill-timed. Thus, it becomes challenging to detect and rectify them on time. Supply chain entities are tightly linked at inter- and intra-enterprise levels and affect each other in many ways. These links complicate the detection, root-cause analysis, and rectification of disruptions. Furthermore, the rectification decisions are often driven by self-interests of the affected entities, which also causes difficulty in their implementation. Therefore, there is a clear need for a systematic approach to disruption management in supply chains, which would

detect the disruptions before they occur, quantify them, locate their root causes, and identify the best rectification strategies. Having an intelligent system that can rectify a disruption fully or partially is certainly preferable.

Disruptions can occur in many forms and can affect supply chains at various levels such as operations, intra-enterprise, inter-enterprise, etc. The difficulty in handling them increases at higher levels.

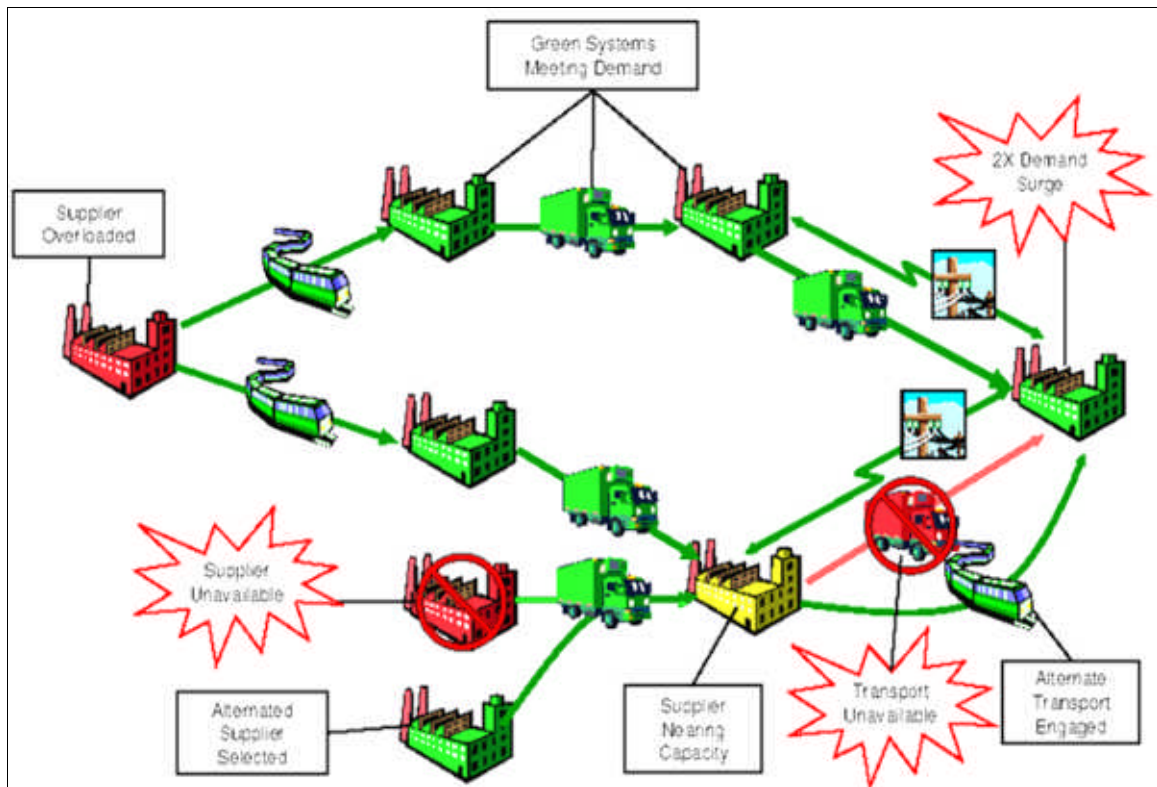


Figure 1.1 Disruptions in supply Chain

## 1.1 Classification of disruptions

The flows in a supply chain can be classified as those of material, information, and finance. Blockage in any flow can create a disruption. We classify disruptions according to their flows.

*Disruption in material flow:* In a supply chain, if an entity is unable to deliver raw materials or products, then it is a disruption in material flow. Such a disruption is highly probable at the inter-enterprise levels in complex and big supply chain networks. It can arise due to operational difficulties, supplier overload, unavailability of supplier, transport delays, unavailability of storage or processing facilities, abnormal demand fluctuations, etc.

*Disruption in information flow:* Like the disruption in material flow, this can also occur at all three levels of a supply chain. It arises due to the unavailability or misinterpretation of required information by any entity, which affects the coordination among the entities and disrupts the supply chain. It may also arise due to human or computational errors.

*Disruption in finance flow:* Finance plays a vital role in running an enterprise. The unavailability of finance in a supply chain entity can affect the supply of raw materials, plant operations, delivery of products, etc. In some situations, even when finance is available, an enterprise may be handicapped to get it or to deliver it, and flow of material in the upstream and downstream of supply chain may be disrupted.

While technology developments, promotions, sales incentives, increased variety of products, etc. are some of the reasons for disruptions in supply chains, often, the roots of disruptions lay in management strategies. Here, we list four common strategies, which may lead to disruptions:

1. Outsourcing increases the numbers of entities and links in a supply chain and makes the supply chain more complex, lengthy, and vulnerable.

2. The policy of using preferred suppliers reduces the supplier database significantly and sometimes results in the unavailability of suppliers.
3. The practice of centralized distribution in order to manufacture fewer products at a single site rather than a full range of products at each site may increase the transport distances of raw materials and products and may give rise to inflexibility in a supply chain.
4. Lack of visibility in complex and lengthy supply chains causes inadequate forecast for planning. This may cause deviation between actual and planned operation and may some time result in disruptions.

Despite an increase in supply chain disruptions at the levels mentioned above, this intricate problem of disruption management has not been studied widely so far. A few incidents in the last couple of years, like terrorist attacks, natural disasters, etc. have drawn the attention of supply chain managers and researchers (Yossi Sheffi (2003), Gaonkar et al. (2004)) towards the security and resilience of supply chains. Some literature is available in the field of risk management and researchers have started addressing disruptions in supply chains.

## ***1.2 Outline of the thesis***

In this work, we present a Decision Support System (DSS) for disruption management. Similar to fault detection in a chemical plant, the system requires continuous performance monitoring. We adopt Feedforward and Feedback, both approaches for this purpose, which makes the system more efficient and prompt in detecting disruptions. In this work, we present the details of the framework, its implementation, and its application to a refinery supply chain.

The system under consideration can be broken into three parts, namely: supply chain, supply chain model, and disruptions management system. The interaction of the system can be understood from Figure 1.2. The supply chain is basically a real supply chain and it is modeled using agent-based technique and uses data from the real supply chain. The disruptions management system (DMS) which is basically decision support system for disruption management is also modeled using agent-based technique. DMS interfaces both the supply chain model and supply chain. It can request the required information from supply chain model as well as it can suggest corrective actions to the supply chain. The details of the framework are provided in chapter 3.

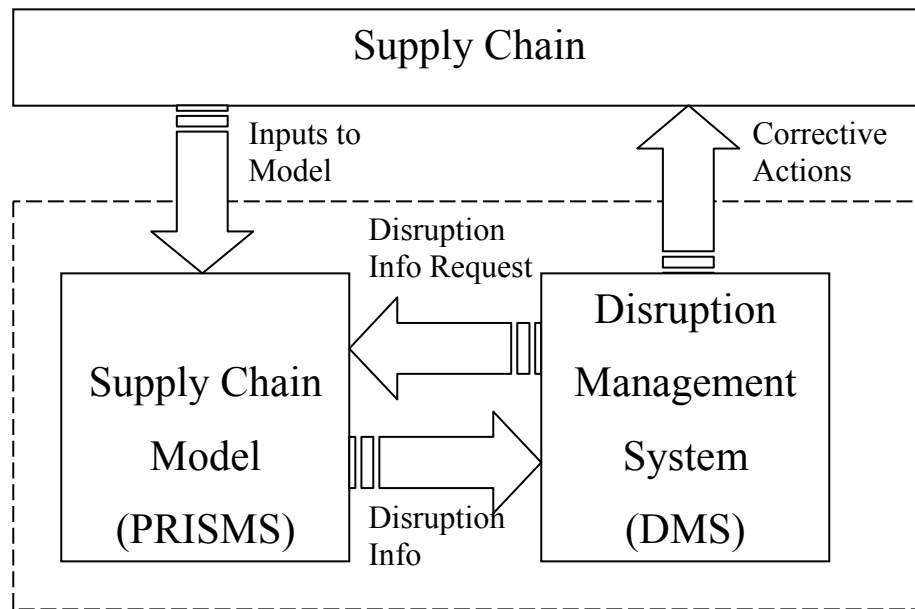


Figure 1.2: Overview of proposed disruption management framework

The thesis is organized as follows. Chapter 2 critically assesses agent-based techniques, their applications, and the existing literature on disruptions in supply chains. Chapter 3 describes the challenges involved in handling disruptions and the methodology for disruption management. It discusses the proposed approach and framework for



detection, diagnosis, and management of disruptions. Chapter 3 also describes about the two approaches for controlling supply chain, namely: feedforward and feedback approach. Chapter 4 illustrates the application of the proposed framework using scenarios arising from transportation delay, abnormal demand fluctuations, crude parcels rejections, and facility operation disruptions in a refinery supply chain. Conclusion and recommendations for future work are given in Chapter 5.

## **Chapter 2 Background and previous work**

In this chapter, we critically assess the existing literature on disruptions and risk management in supply chains. Furthermore, we discuss briefly the techniques for supply chain modeling.

Most of the work has been done in the area of supply chain risk management, which is about the planning of supply chain to make it immune to disruptions. In case risk management fails, disruptions may occur. To make supply chains immune to disruptions, we require proper disruption management system.

### ***2.1 Managing disruptions and risks***

Not much work has been done in the area of disruption management and hence no structured and proven methodology is available for disruption management. Disruptions have received attention of a few researchers. Gaonkar et al. (2004) classify supply chain risks into three forms – deviation, disruption and disaster and propose a framework for handling supply chain risks. They identify that the design of supply chain must be robust at strategic, tactical, and operation levels. According to them deviation in supply chain happens due to deviation in parameters of supply chain and does not change the supply chain structure. Disruption is more severe, where an unexpected event can affect a part of supply chain or flow in supply chain. A disaster is defined as a temporary, irrecoverable shutdown of the supply chain network due to unforeseen catastrophic, system-wide disruptions. In their work, they develop mathematical models for strategic-level deviation as well as disruption management. They address the case study of selecting an optimal group of suppliers.

Lee et al. (2004) discuss that information distortion can be the origin of malfunctions in supply chain. They emphasize on the flow of information and suggest that in a long supply chain the information distortion can be severe and can affect the decision of entities for inventories, production etc. They analyze four sources of information distortion: demand signal processing, rationing game, order batching, and price variations and discuss actions to mitigate the detrimental impact of this distortion. Similarly, Hendricks et al. (2005) see association between supply chain glitches and operating performance. They perform case study based on 885 glitches and find that the glitches in supply chain affects operating income, return on sales, and return on assets. They claim that glitches also affect the growth of the company by resulting into lower sales growth, higher growth in cost, and higher growth in inventories.

For managing disruptions a few articles are available, which suggest various framework, methodologies for managing disruptions. Yossi Sheffi (2003) looked at the mechanism that companies follow to assess terrorism related risks, to protect the supply chain from those risks and to attain resilience, i.e. their preparedness against such disruptions. This paper is based on various case-studies and interviews conducted with some company executives. It contains classification of disruptions and security measures, and brief ideas to achieve resilience in supply chains. Similarly, Xu et al. (2003) addresses the problem of handling the uncertainty of demand in a one-supplier-one-retailer supply chain system. They identify demand variation as a sensitive problem with higher impacts and in their work they present methodology to handle the demand uncertainty in a supply chain, both for the case of a centralized-decision-making system and the case of decentralized-decision-making system with perfect coordination.

Toby (2006) identifies that the disruptions are very much critical to today's supply chain and suggests the ways to avoid supply chain disruption. It is suggested that identifying troubled suppliers, conducting periodic plant tour, monitoring delivery performance, preparing strong contracts can help an enterprise in identifying the possibility of disruptions. He also suggests that the enterprise must be prepared with the alternative suppliers in case of higher possibilities of supply disruption. For managing supply chain risk disruption, Pochard (2003) suggests dual sourcing as a real option. She finds that two types of actions are available to respond to uncertainty: securing the supply chain and developing resilience. She develops an analytic model taking into account various parameters affecting dual sourcing. Based on the results, a few recommendations to help managers build a more resilient supply chain are presented.

Martha and Subbakrishna (2002) suggest that adopting concepts of supply chain management (lean management, just-in-time etc.) must be balanced with the calculated risk to avoid disruptions in supply chain. They suggest that, evaluating the risk, cultivating alternative sourcing arrangement, lining up alternative transportation, shifting the demands by diverting customers, and managing safety stock can help the organizations in dealing with disruption. In the same way, Handfield et al. (2006) present a managerial framework for managing disruptions in supply chain. They interview executives in various companies and discovered several key themes associated with supply chain disruptions. They provide suggestions for building the supply chain strategies which can help the companies in reducing the impact of disruptions and can help in managing the disruptions also.

Transportation disruption, a key attention of researchers in this area has drawn some attention. Adhitya (2005) proposes heuristic strategy for handling transportation disruptions in refinery. He identifies that the significantly large amount of time taken for generating (near) optimal schedules is undesirable while dealing with disruption, it also analyses that changing the problem data in existing scheduling approaches results in substantially different schedules. Hence, he proposes heuristic rescheduling strategy for recovering from disruptions that overcomes both these shortcomings. He breaks the schedule into operation blocks and performs rescheduling by modifying these blocks in the original schedule using simple heuristics, and generates a new schedule for the new problem data. The proposed method can be used for real-time system and minimizes the changes to operations in comparison with total rescheduling. He implements the method on five types of disruptions in a refinery supply chain.

Abumaizar and Svestka, (1997) also present an algorithm for rescheduling the affected operations in a job shop. They measure performance, in terms of efficiency and stability, and compare with that of Total Rescheduling and Right-Shift Rescheduling. Through the results of the case-studies they demonstrate that the Affected Operations Algorithm overcomes the disadvantages associated with other rescheduling methods.

Recently, there has been some interest in the area of risk management in supply chains. Generally, risk management consists of actions taken to strengthen a supply chain against possible disruptions. Kleindorfer et al. (2003) discuss risk management in global supply chains related to supply-demand coordination risks and disruption risks. In their study, they discuss ways to identify these risks and various strategies to manage them. Landeghem and Vanmaele (2002) apply risk management to tactical planning level

within demand and supply chains, and present a concept of robust supply chains. They employ Monte Carlo simulation for accurate tactical planning decisions. They determine logistics set points in such a way that unforeseen conditions will be less likely to affect the performance of supply chains. Their approach helps in making supply chains more effective with less re-planning and smaller safety stock. Harland et al. (2003) discuss various types of risks, their assessment and management. They briefly touch upon the reasons for the growing complexity of supply chains. Then, they describe the various risks in supply networks and propose a tool for identifying, assessing, and managing them. A case-study on supply networks of Hi-Tech products is presented to evaluate the performance of these risk tools. Ulf Paulsson (2003) reviews the work done on risk management in supply chains and concludes that only twenty two scientific articles exist on risk management. He discusses the background, objective, methods, and results for selecting the relevant work. His paper also shows that risk management is becoming important and gaining attention of researchers. In our opinion, risk management is different from disruption management and it is important to handle both problems differently for effective solutions.

## ***2.2 Supply Chain Modeling***

Supply chains are distributed, disparate, dynamic in nature. This makes their modeling with mathematical formulations quite cumbersome. Julka et al. (2002 a, b) show that an agent-based technique is very effective in modeling such systems. This technique is able to accommodate all the aforementioned features of supply chain. In this section, we review agent-based techniques with reference to the modeling of supply chains and negotiation protocols among the agents.

To make decisions using an agent-based method, we must model agents, define their activities, and identify their interactions. Julka et al. (2002; a, b) proposed an agent-based framework for decision support in supply chain management and its application to a refinery supply chain. In this framework, every entity is modeled as an agent and the agents imitate the behavior of entities (procurement, operations, sales, etc.). The agents have a number of well-defined activities and they communicate with one another using messages. Agent-based techniques are used in distributed and dynamic environments, where optimal decision-making is difficult. Since the agents are driven by self-interest, we can use coalition, collaboration and negotiation among agents to seek the optimal decision. Similarly, Srinivasan et al. (2006) present a multi-agent approach for supply chain management in chemical industry. In this work, they describe an agent-based model for a refinery supply chain. In this model, the agents emulate the departments of the refinery as well as other entities associated to refinery's supply chain. These agents modeled to incorporate the business policies and made to imitate the different business processes of refinery and also capture uncertainties. This work provides decision support for structure and parameters of the supply chain.

Sirola et al. (2003) propose collaboration among agents for defining the activities of agents and their strategies of interaction. They take an optimization problem and try to solve it using different methods of collaborating behavior. They identify three types (operator, selection, and meta) of agents depending upon their behaviors. Central executive ranks the agents according to various criteria (problem solving ability, time on queue, performance, etc.) and then calls them accordingly. Different agents take initial values from a shared memory database and post results on the same shared memory

database. This way, they use the results obtained by other agents as their initial values. Some agents use the initial values and generate intermediate results that are used by other agents to obtain the final outcome. In this way, the collaboration among agents is justified. We believe that this method cannot handle supply chain disruptions because the type of collaboration among agents is completely different in disruptions. The agents collaborate with other agents in the midst of activities. Furthermore, negotiation is not possible among agents, while implementing a corrective action.

Hon et al. (2003) propose a well-structured algorithm for negotiation in dynamic scheduling and rescheduling. The main components of their algorithm are user preference model, utility function, initiating agent, collaborating agents, negotiation protocol, and negotiation algorithm. All the agents are given preference level and priority to support decisions during negotiation. Utility functions and model preference are used for this purpose. The algorithm is robust enough to solve negotiation problems in scheduling. However, the level of complexity used in this method is different from that in supply chain disruptions, and hence, such algorithms are not useful in managing supply chain disruptions.

Hung et al. (2005) present a new modeling approach for realistic simulation of supply-chains. This model is based on an object-oriented architecture to give flexibility to the supply chain configuration. A model of a generic supply-chain node is developed to capture the features present in supply-chain entities and the activities of the entities are also modeled with in it. Model can perform fully dynamic simulation of the supply-chain and the effect of various uncertainties can be evaluated. The case study presented demonstrates the effect of policy changes on the supply-chain performance.



Sheremetov et al. (2004) propose a contingency management system (CMS) based on a multi-agent approach. They apply this approach for the development of the CMS for the oil complexes in the marine zone of a gulf and focus on logistics planning for evacuating personnel. They use coalition formation techniques with fuzzy knowledge acquisition to make optimal decisions in the CMS.

Some work addresses disruptions in common supply chains. Hyung et al. (2003) discuss changing situations in supply chains in computer industries and propose a flexible agent-based system to counter this problem. This method is quite suitable for computer supply chains but not for chemical industries. Yuhong et al. (2000) use an agent-based model to support project management in a distributed environment. In this model, an agent represents each activity and resource needed in a project. These agents are classified as activity agents, resource agents, and service agents, which are then used by strategies to solve the main problem of project management. The methodology is tested using a case-study on a new project of a computer company. Kwang-Jong et al. (2003) propose an agent-based negotiation system for changing market situations by adjusting concession rates. To determine the amount of concession for each trading cycle, the agents follow four mathematical functions based on eagerness of agents to trade, remaining trading time, trading opportunity, and competition. The authors formulate market-driven strategies for negotiation. However, their system is not suited for solving problems associated with enterprises and consumers. Aldea et al. (2004) present a multi-agent methodology for process industry applications. They test the system on three different applications - intelligent search system, concurrent design system, and

configuration of team work. While the system is efficient for scenarios, it cannot work for uncertain cases such as disruptions due to the inadequate degree of freedom.

Huaiqing et al. (2002) present constraint language technique for agent modeling and negotiation among agents. They classify constraints as hard and soft and then satisfy all the hard constraints, minimize soft constraint violations and maximize the sum of all objective functions. A case-study on scheduling switched capacitors in power distribution systems is done. Ovalle and Marquez (2003) try to show the effect of e-collaboration or information sharing among the supply chain entities locally as well as globally. They share three types of information - product information, customer demand and transaction information, and inventory information. The effect of collaboration is illustrated with an increased service level, decreased global average cash requirement, and stable goods inventories at supplier and manufacturer locations. The results are proved by taking a case-study with four trading partners: factory, distributor, wholesaler, and retailer. Samuel et al. (2001) propose an agent-based negotiation system based on genetic algorithm. Negotiation is constraint-based and the constraints follow the fundamentals of genetic algorithm. Sousa and Ramos (1999) describe Halonic manufacturing system. A halon is autonomous, co-operative, and sometimes intelligent. The authors use this system to address a problem related to scheduling in a Halonic manufacturing system. This system can deal with conflicts in scheduling by assigning operations to the resources of the manufacturing system. In case of 'indecision problem', the system involves re-negotiation. Dongming et al. (2002) present a multi-agent collaboration system for business-to-business applications. The system can identify work flow problems and solve

these problems by applying business rules like re-organizing procurement and transaction processes and making changes in the workflow process.

In the next chapter, we describe our framework for supply chain disruption management and discuss its advantages. We then implement and demonstrate it on a model (PRISMS – Petroleum Refinery Supply chain Modeler and Simulator, Julka et al., 2002b) for refinery supply chain.

## Chapter 3 Framework for disruption management

Figure 3.1 presents our proposed general framework for disruption detection and management in supply chains. It is inspired from the existing literature on fault detection and rectification of process networks. An integral part of the disruption management system is a model for the real supply chain under observation as shown in Figure 3.1.

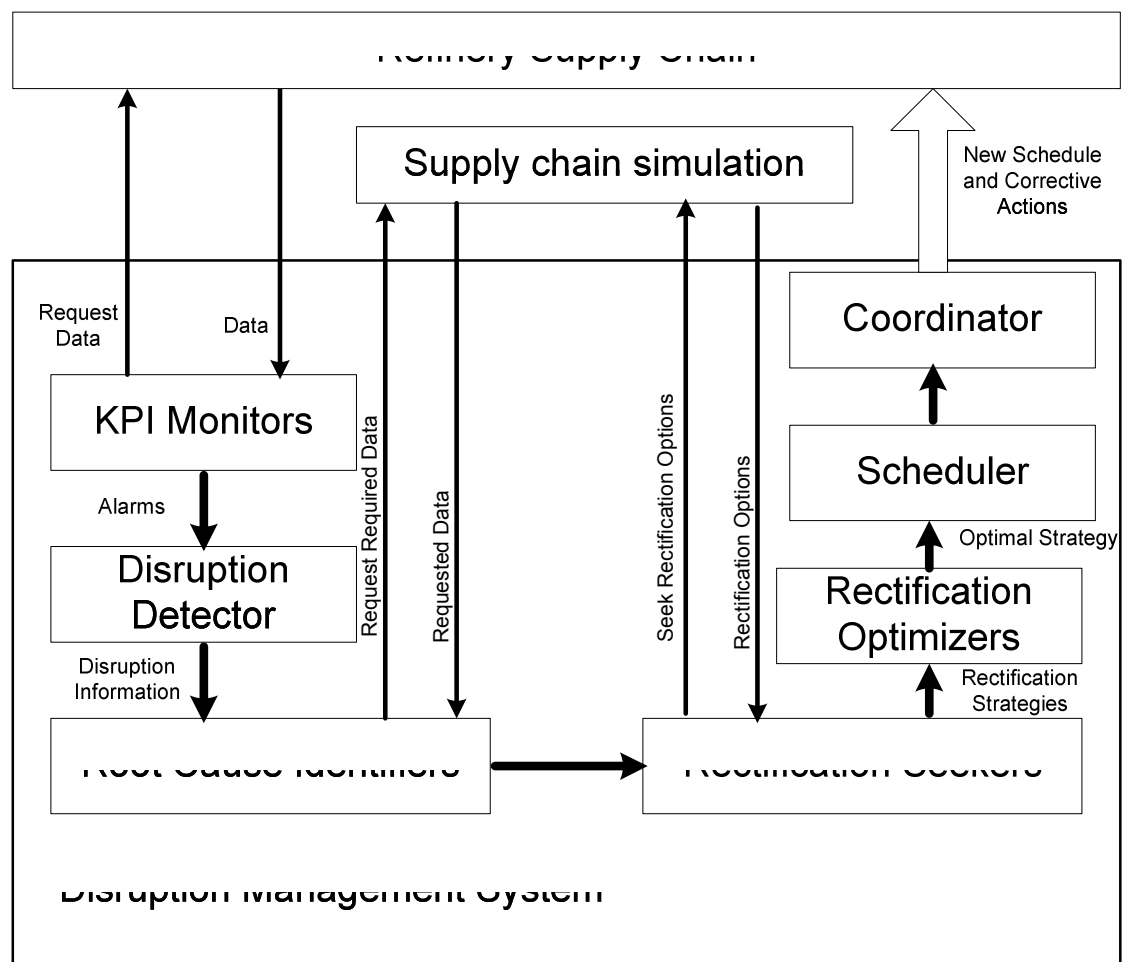


Figure 3.1: Framework for disruption management

### ***3.1 Components of Framework***

To detect disruptions in a supply chain, we need to monitor its entities, their activities, and their performance. A supply chain usually generates a tremendous volume of data and tracking all this information is a cumbersome job. For managing disruptions, we need to know the effects of any disruption or corrective action on supply chain entities. Hence, we need a Supply Chain Modeler and Simulator (SCMS) that can simulate different scenarios. SCMS interfaces with both supply chain and Disruption Management System (DMS). It receives all the required information from the supply chain, like inventory profiles, transportation schedules, operational details, sales information, etc. Information related to each and every event among the entities in a supply chain is transferred to SCMS. The responsibility of SCMS is to model the supply chain entities and their activities, simulate the supply chain as a real-time system, and pass appropriate information to DMS for continuous performance monitoring of the supply chain and disruption management.

Various techniques exist for modeling and simulating a supply chain; we use an agent-based technique for this purpose. For any supply chain to operate smoothly, all its entities must perform their activities without any disruptions. A disruption will affect supply chain performance in one form or another and its effects will manifest itself in terms of key performance indices (KPIs) for the supply chain. Therefore, to detect disruptions, we continuously monitor several KPIs of the supply chain and its entities as follows.

A KPI is a function of several activities in a supply chain. Inventory levels, order fill rate, etc. are some examples of KPIs. For example, inventory profile is a measure of the

performance of transportation, storage department, production, and demand. Therefore, to assess the performance of the supply chain, KPI must be continuously monitored. All the entities which are interested in determining their performance are required to be monitored for the related KPI. For example, inventory profile can be monitored by storage, 3PLs, procurement etc. If any entity finds disturbances (deviations from assigned limits) in the associated KPI; it can step forward towards the rectification of disturbances. A KPI informs about the performance of multiple entities, and multiple entities monitor a KPI, these kinds of many-to-many relationships form a complex network that gives rise to ambiguity in identifying the root causes of any change in a KPI. By continuously monitoring the KPIs, we can detect their deviations from the norms. Once these symptoms are observed, the next challenge is to verify the disruption and find its root cause. To this end, the KPI change is forwarded to the Disruption Management System (DMS). DMS interfaces with both the Supply Chain (SC) and the Supply Chain Modeler and Simulator (SCMS) for managing a disruption. As shown in Figure 3.1 and Figure 3.2, the methodology for disruption management consists of the following steps:

1. Monitoring of supply chain
2. Detection of disruption
3. Finding root cause
4. Finding rectification strategies
5. Finding optimal strategy
6. Implementation of best rectification strategy

We now explain each step in detail.

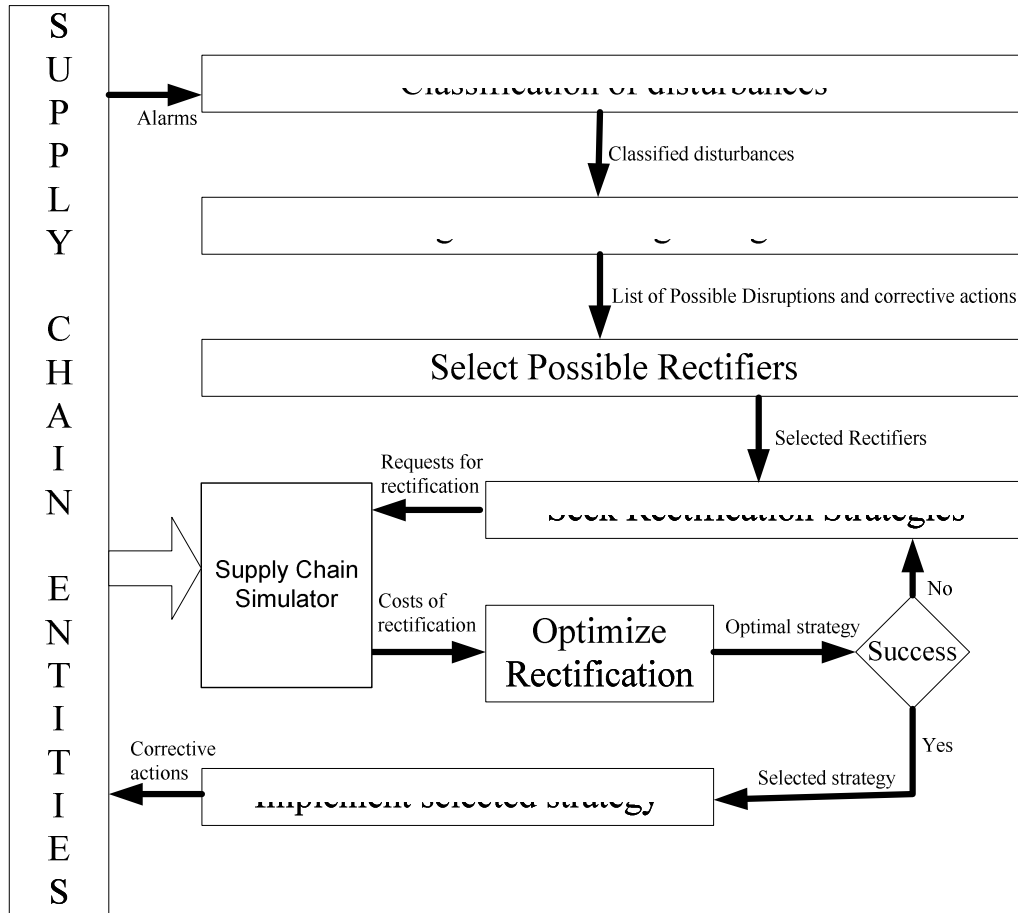


Figure 3.2: Information flow for disruption management system

### 3.1.1 Detection of disruption

Every supply chain comprises several entities and each entity has a number of defined activities. The combined performance of these activities is the measure of performance of the whole supply chain. The KPI monitors continuously monitor these activities in terms of several KPIs. Figure 3.3 shows the mapping of the interaction of supply chain entities and KPI monitors. From the figure, we see that more than one monitor can monitor an activity of supply chain. Similarly, one KPI monitor can monitor more than one activity. When a KPI deviates beyond specified norms, a disruption is

detected and alarms are generated. Monitoring is done to check the KPIs are in some limits as follows:

$$\hat{KPI}_k = 1 \text{ if } KPI_k > KPI_k^U \text{ or } KPI_k < KPI_k^L \text{ else } \hat{KPI}_k = 0$$

If  $\hat{KPI}_k = 1$  then alarms are generated as symptoms of disruption and  $\hat{KPI}_k$  is the abnormal KPI.

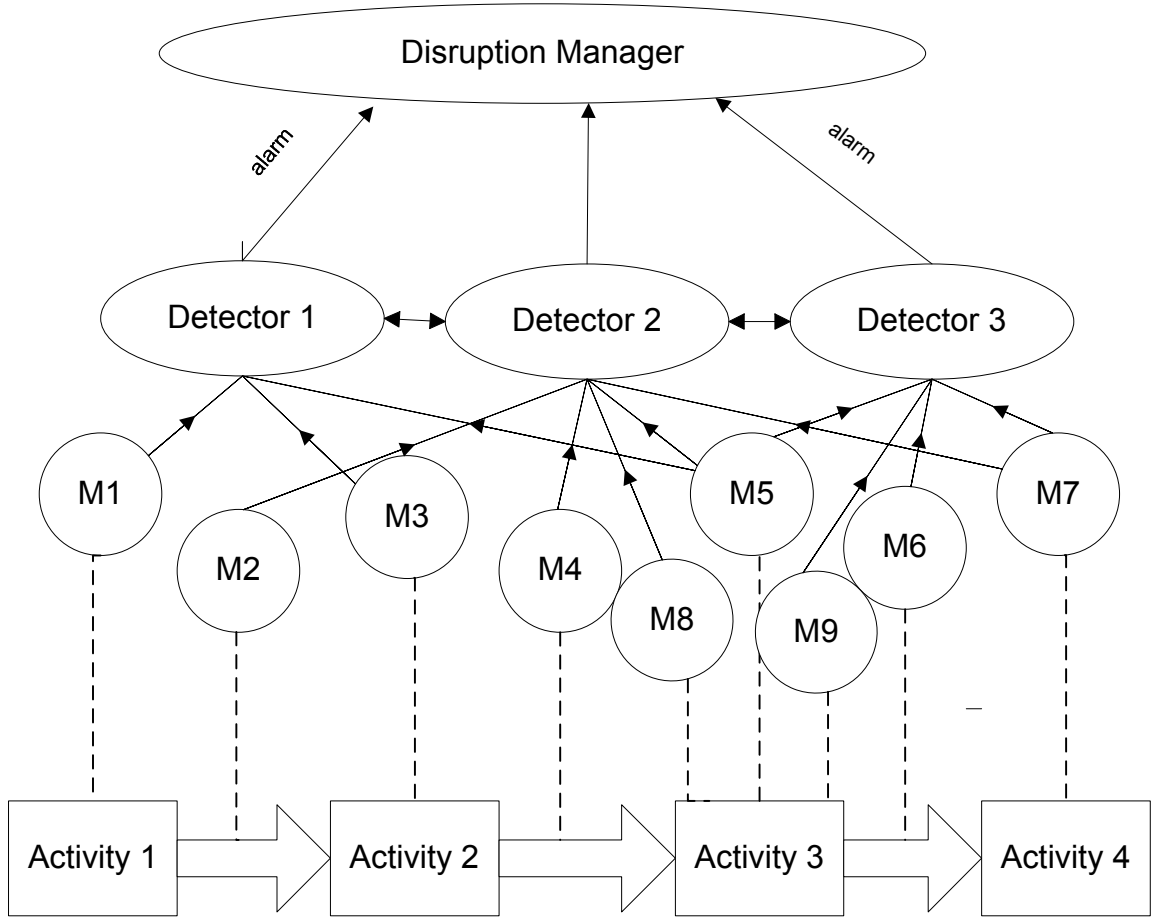


Figure 3.3: Monitoring system for disruption detection

### 3.1.2 Event driven detection

For detection of disruption, event driven detection is applied in the framework. Hence, the supply chain itself needs to figure out the deviations in its KPIs. The disruption is detected on the basis of criticality assessment of the abnormal event. Any



abnormal event which has impact on any kind of flow in supply chain has to go through the criticality assessment for disruption. Criticality assessment is a check which is performed along the flow in the supply chain with the new data point set by the abnormal event. If the check suggests any possibility of disruption in supply chain then the information is immediately forwarded to rectification strategy seeker agent to gather the rectification options from different entities in supply chain.

### 3.1.3 Root cause identification

The root cause of a disruption in supply chain may not be obvious, because of the complex many-to-many relationships among the entities and the KPIs. So, once we detect the disruption, we can reach the root cause by back tracking the sequence of events. The relationship of activities in supply chain and KPI as follows:

$$KPI_k = \sum_a f_{ka}(\alpha_i^a v_i) \quad \forall i$$

Hence, a KPI is summation of effects from all the activities in a supply chain.  $v_i$  is a measured variable and  $\alpha_i^a$  a fraction which describes its affect on the KPI. A variable is active in an activity in a KPI only if  $\alpha_i^a \neq 0$  for that variable for that particular activity. We can find out the set of variables which have  $\alpha_i^a \neq 0$  and the associated activities. Now, we find all the KPIs which have these activities in them and check the fluctuations in those. In this way we arrive on the culprit activity which is the root cause.

The abovementioned is the basic principle for root cause diagnosis; however we can diagnose the root cause by various methods. Two different methods are given below:

### 3.1.3.1 Model-based root cause detection:

This method uses model-based technique to identify the links between the activities and the KPIs. We can explain this method using Figure 3.4. In this technique we can model possible symptoms in the supply chain and all the possible activities which can cause these symptoms. Since a symptom can be caused by multiple activities, to find the culprit activity is difficult. Hence, we need to measure the quantitative and qualitative effect of the activities on the symptom. The decision of root cause can be final only after analyzing all the activities linking to the symptom. For example, if the symptom is inventory low, then the linked activities are transportation, demand, production. Qualitative effects are delay in transportation, rise in demand, and throughput change in production. Quantitative effects can be measured by doing basic mass balance. Hence, after analyzing all the activities the root cause is confirmed.

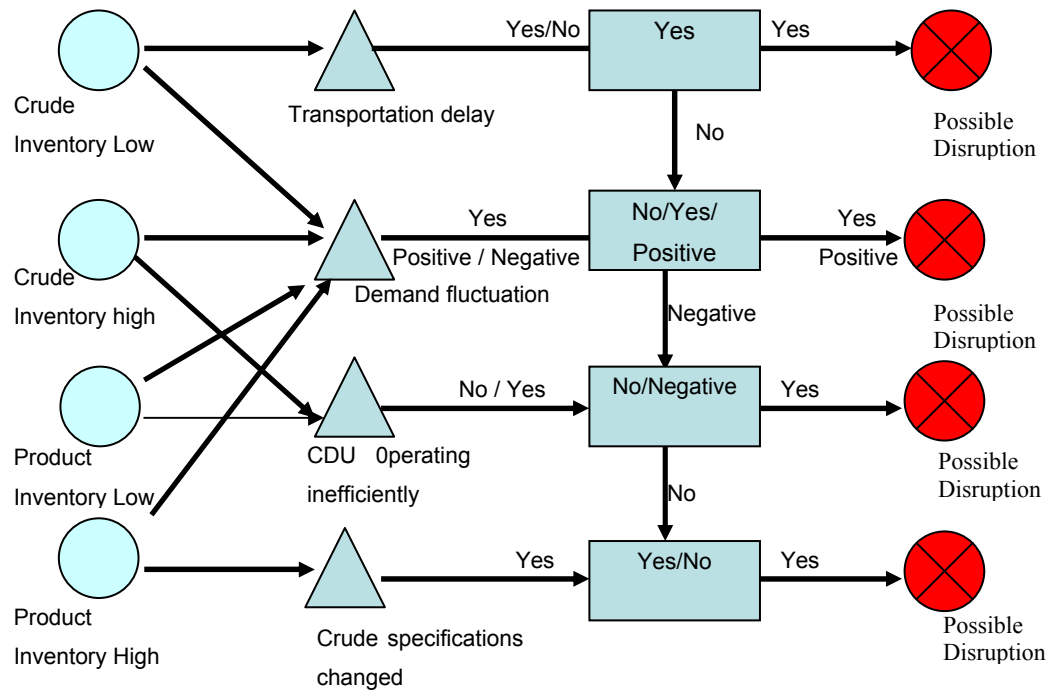


Figure 3.4: Causal model based root cause diagnosis

### *3.1.3.2 Rule-based root cause detection:*

Rule-based method has a database which keeps all the entities, their activities, KPIs, and their relationships. For every symptom, the related activities are also listed. Once the symptom is found all the respective activities are checked for their performance. Ill-performance found in any activity indicates that the activity may be a possible root cause. The entities responsible for this activity are checked again to confirm disruption.

DMS uses a rule-based approach for root cause diagnosis. If malfunction in a KPI is detected, it traces the activities that could cause similar effect. As the number of these activities can be more than one, we need to confirm which entity and which activity is the real cause of disruption. So, DMS further investigates the performance of other activities of each entity short-listed, and if it finds some activity which leads to same deviation in the KPI, it concludes that activity as root cause of disruption. For example, say deviation (low) is detected in inventory profile of a product. The DMS can find that the associated activities are transportation delay of the raw material, under production of product due to operational problems, and high sales of the product. Then it shortlists the related departments are as Logistics Department, Operations Department and Sales Department. Then it checks the other activities of these departments, for example it checks the transportation details of Logistics department and may find that the shipment of raw material has been delayed by a certain time. Thus after calculating the effect on the product stock, it can conclude that the root cause for disruption is transportation delay.

### 3.1.4 Seek rectification strategies

Once the root cause is identified, the next step is to figure out all the rectification strategies to recover from the disruption. From previous steps, we get the root cause and the affected KPI.

$$KPI_k = \sum_a f_{ka}(\alpha_i^a v_i) \quad \forall i$$

as KPI is summation of the effects by activities, any activity other than the root cause can help the disrupted KPI to recover from disruption. Hence, it is needed to find all other activities which can help the KPI to recover. We define this set **AROK**.

**AROK**= set of activities (activity a) such that  $\alpha_i^a \neq 0$  – activity which is root cause

All the entities which perform activities in **AROK** are contacted and rectifications are requested. We can define this set of entities as **EROK**.

In reply each Entity  $E_j$  offers the extent of recovery  $\Delta KPI_{kj}$  and cost of recovery  $COR_j$ .

Where  $E_j \in \mathbf{EROK}$

$\Delta KPI_{kj}$  = Possible difference in  $KPI_k$  resulting from rectification option offered by  $E_j$ .

$COR_j$ . = cost of rectification of rectification offered by  $E_j$ .

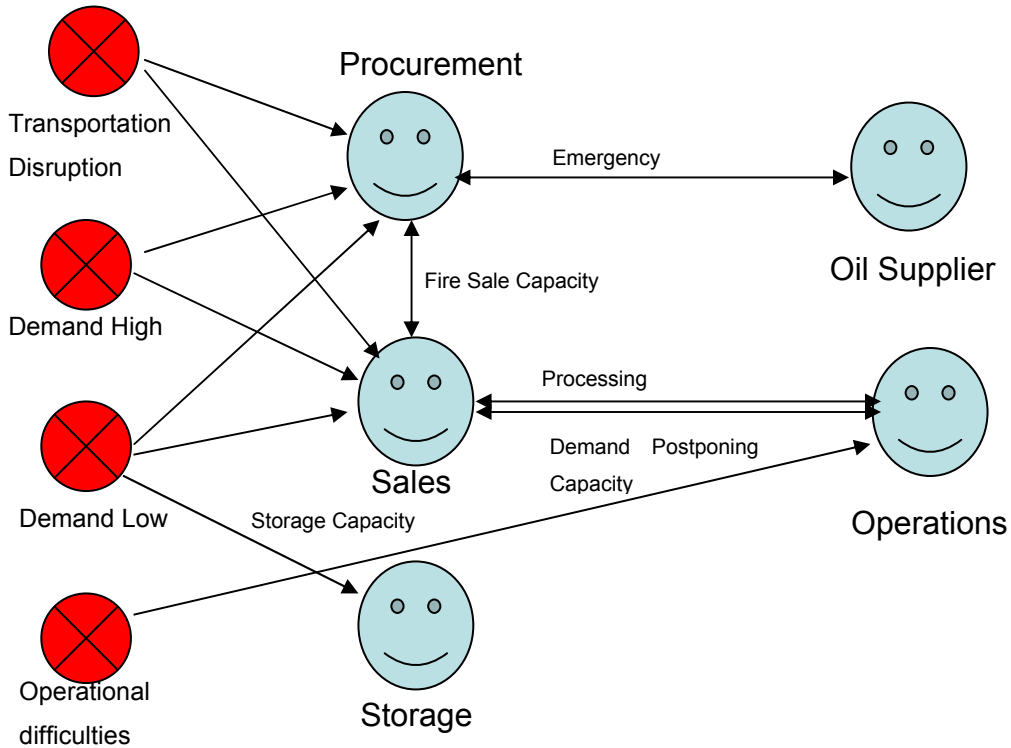


Figure 3.5: Model based rectification options seeking

In DMS, we scrutinize the material and information flows along the SC and identify the entities that have roles to play. In Figure 3.5, the pictorial view of the rectification strategy seeking process is shown. For example, in case of a transportation disruption in a refinery, the immediate effect is shortage of crude. The shortage of crude can cause operational discontinuity, change in operation schedule, and delay in product delivery. Hence, we identify that the entities that can be affected are crude procurement (for procuring emergency crude), operations (to change operation schedule), and sales (to deal with the delay in delivery). So the rectification options shall be requested from these three entities only.

### 3.1.5 Selection of optimal strategy

For any given disruption, several rectification options may exist and combinations of these rectification options can form multiple rectification strategies. As these rectification strategies may have different solutions and can have different effects on supply chain, we need to find the best possible rectification strategy before implementing the options. The rectification option offered by one entity can be opposite or supplementary to an option offered by some other entity, so it is necessary that while forming a rectification strategy or while analyzing an option, we account for other associated options also with this option. The optimal rectification option would be maximizing recovery in  $KPI_k$  and minimizing the cost of rectification. We define the objective function for optimization as follows:

$$f_{rs} = \sum_j \Delta KPI_j \times FU_j - \sum_j COR_j \times FU_j$$

$f_{rs}$  is the objective function for optimization of rectification strategy and  $FU_j$  is the fractional utilization of rectification offered by  $E_j$ . We need to find out the values  $FU_j$  to get the rectification strategy.

In DMS, the cost of rectification is in the form of preference based model. The model is based on the preferences practiced by the entities. For example the emergency procurement is preferred over the shut-down of the operation units. As all the entities are running on a schedule and strategies, and changing these things by shutting down the units can cause cost to other entities. So in a selected strategy we may find the maximum utilization of the most preferred rectification option and may be the least preferred option remains unused.

### *3.1.6 Implementation of the strategy*

Once the disruption management system identifies an optimal rectification strategy, the rectification strategy is implemented on the SC. The entities of supply chains are self-interested and have limited operational flexibility. This rigid operational set up makes implementation of the strategy a difficult job. In real life, every entity in supply chain generally operates at a set point and has limitations on deviations. Changes in the operating set points are generally not acceptable to the entities. Thus a need arises for negotiation among the entities to solve the differences in accepting the rectification options. By negotiation, entities can be motivated to accept the rectification strategy. There can be a case where an entity offers a rectification option at its full potential and when it gets the option for implementation, it loses the potential to deliver that option. In this case, the entity can use negotiation to exchange the rectification option or request complementary options from other entities. In this way, negotiation plays a vital role in arriving at a common solution and implementing the rectification strategy.

### *3.1.7 Resilience index*

The success of a disruption management system can be measured by the resilience of supply chain in the form of percent recovery from possible disruption. Upon the detection of disruption we can calculate the potential losses due to that disruption. We can also figure out the amount of recovery required from the rectification actions to counter these losses and to ensure that the supply chain is unaffected. After implementing the rectification strategies, we recover from possible disruption up to an extent. We can calculate this amount of recovery also. Then, we compare this attained recovery with the required recovery in terms of the resilience index,

$$\text{Resilience Index} = \frac{\text{Recovery attained}}{\text{Recovery required}}$$

### ***3.2 Feedforward and feedback control***

The efficiency of disruption management system heavily depends on the timely availability of accurate information. In our system, we identify two different types of methods to monitor and control the supply chains, namely feedforward and feedback control approaches. We assess the effectiveness of both the methods are different for different scenarios of disruption. Here, we describe both the methodologies in detail and try to differentiate clearly between the two.

#### ***3.2.1 Feedforward control approach***

Figure 3.6 shows a typical block diagram of feedforward control system for a process. The objective of feedforward system is to keep the controlled variable at a desired set point. The figure shows that if a disturbance occurs, the controlled variable can deviate from its value. A feedforward control law is used to compensate for the effect that a measured disturbance variable may have on the controlled variable. The basic idea is to measure a disturbance directly and take control action to eliminate its impact on the process output. The efficacy of the scheme depends on the accuracy of the process and disturbance models used to describe the system dynamics. Feedforward control can potentially eliminate the effect of a disturbance and lead to perfect control. Because of inaccurate model and unmeasured / unknown disturbances perfect control may not be realizable in practice.



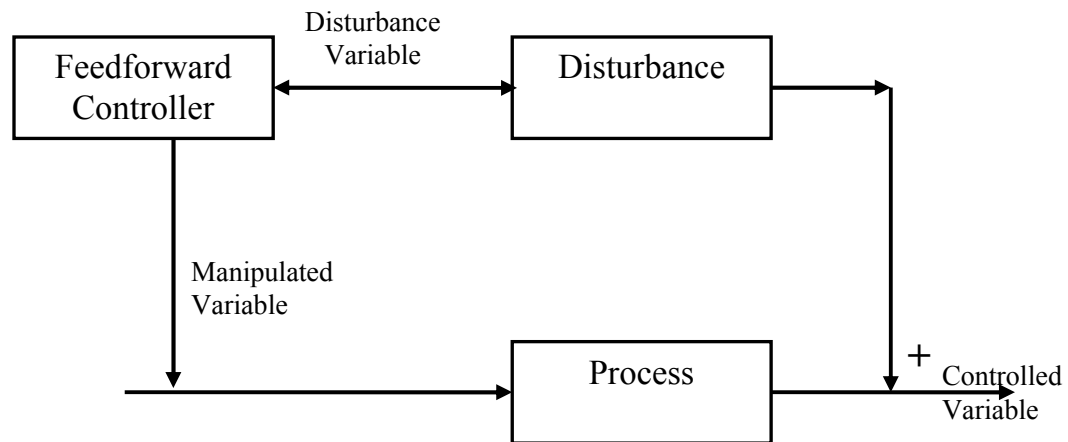


Figure 3.6: Feedforward control block diagram for a process

Figure 3.7 shows feedforward control for supply chain based on similar analogy. This approach is based on capturing the unexpected events in the supply chain and then evaluating their impact on supply chain. So when any unexpected event occurs, criticality assessment is performed to measure the impact of the activity on the level of KPIs of supply chain. In case a critical deviation is detected, it is identified as disruption and the activities for controlling the disruption are kicked-off. The key benefit for having this control methodology is that, the desired level of supply chain control can be achieved without disrupting the supply chain. It provides the solution before the disruption takes place. But the inaccuracy in the model or information can reduce effectiveness of control. So, to implement this methodology to supply chain, the foremost requirements are, accurate modeling, efficient data interfacing of supply chain model to the real supply chain, and accurate information about the disturbance.

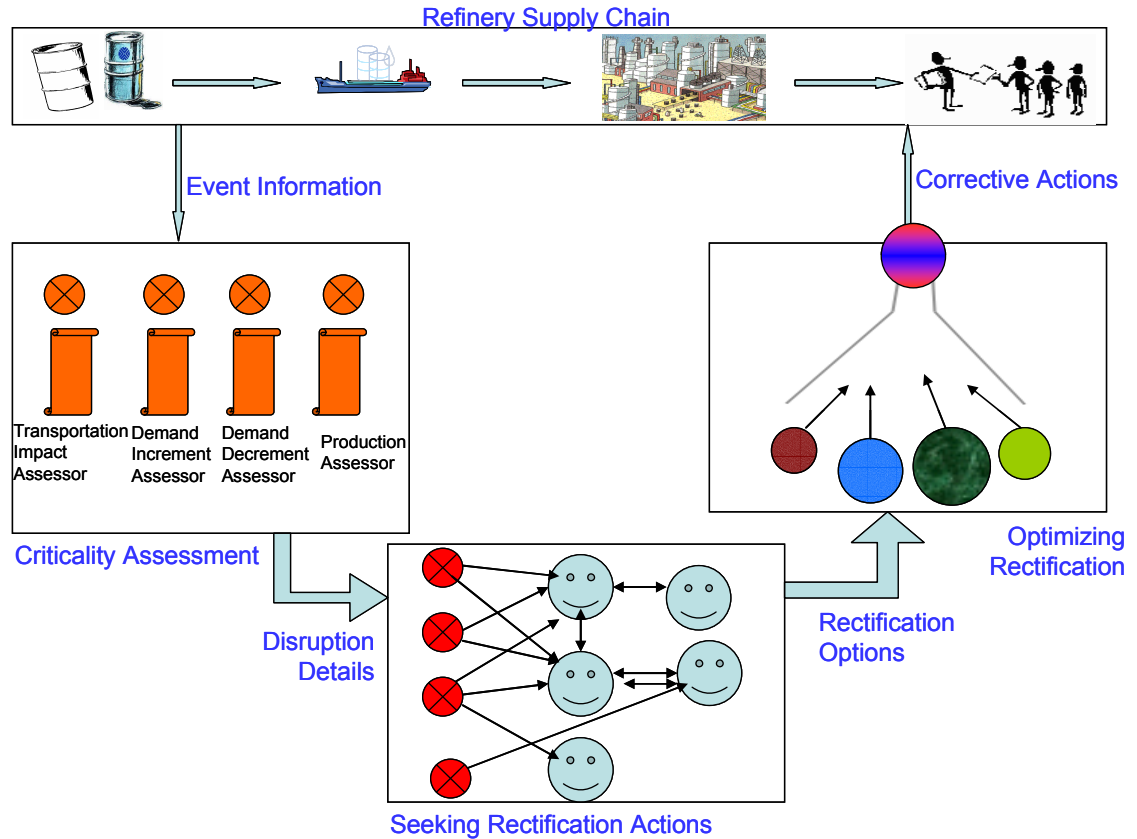


Figure 3.7: Feedforward approach for managing disruptions in supply chain

### 3.2.2 Feedback control approach

Feedback control requires measurement of the effect, not the disturbance. From the block diagram provided in Figure 3.8 it can be seen that mismatch of the controlled variable from the set point (SP) is measured, which is shown as error. After computing the error, the objective of the controller is to adjust the measured variable to ensure that the desired level of operation is obtained; hence the error is minimized to target value of zero. The feedback controller can be used to compensate for any model errors; unmeasured disturbances etc. and ensure offset free control.

We apply above mentioned technique to the supply chain and find this methodology very effective. Figure 3.9 demonstrates a supply chain with feedback control on it. The

feedback control of the supply chain requires strong monitoring of the KPIs, so that the deviation from the desired values is measured accurately. All the KPIs are measured, and if the deviation is detected, then it is required to find out reason for the deviation and the variable which can be manipulated to get the deviated KPI on the desired set point.

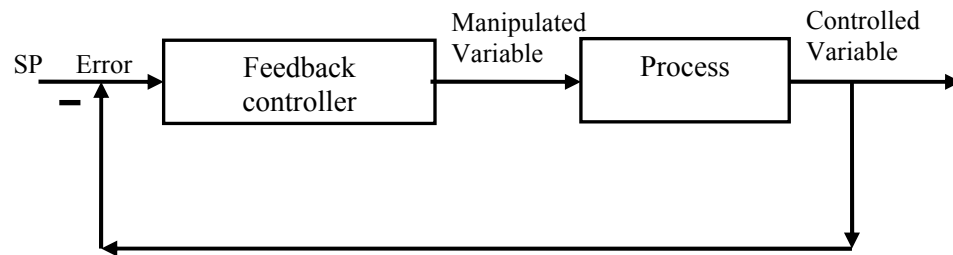


Figure 3.8: Feedback control block diagram for a process

For detecting the reason, root-cause analysis is performed and we use causal model based approach for this purpose. As shown in Figure 3.9 the effects on the KPIs are matched with the possible causes. Possible causes are further explored by investigating the entities for status of events related to the causes. Once the status of all the events is found, the root cause can be concluded. The detailed description of model-based root cause diagnosis has been presented above. After the root cause is detected, the rectification action seeking is performed as it is done in feedforward control system. The received rectification options are optimized and corrective actions are implemented on the supply chain. The advantage of having this control methodology is that the effects of the events which are completely unknown to the supply chain model can be captured and it can be cancelled by DMS. Hence, the supply chain is more robust and prepared for any unforeseen events. In real life supply chain, it possible that the abnormal event happens and the impact assessment of the event is not performed, so the corrective actions are not

taken on time. With feedback control, the effect of those events can be tracked, possible disruption can be captured, and the recovery from that disruption is possible. The drawback of the methodology is that, it rectifies the disruptions after it takes place, so the efficacy of the rectification options is reduced.

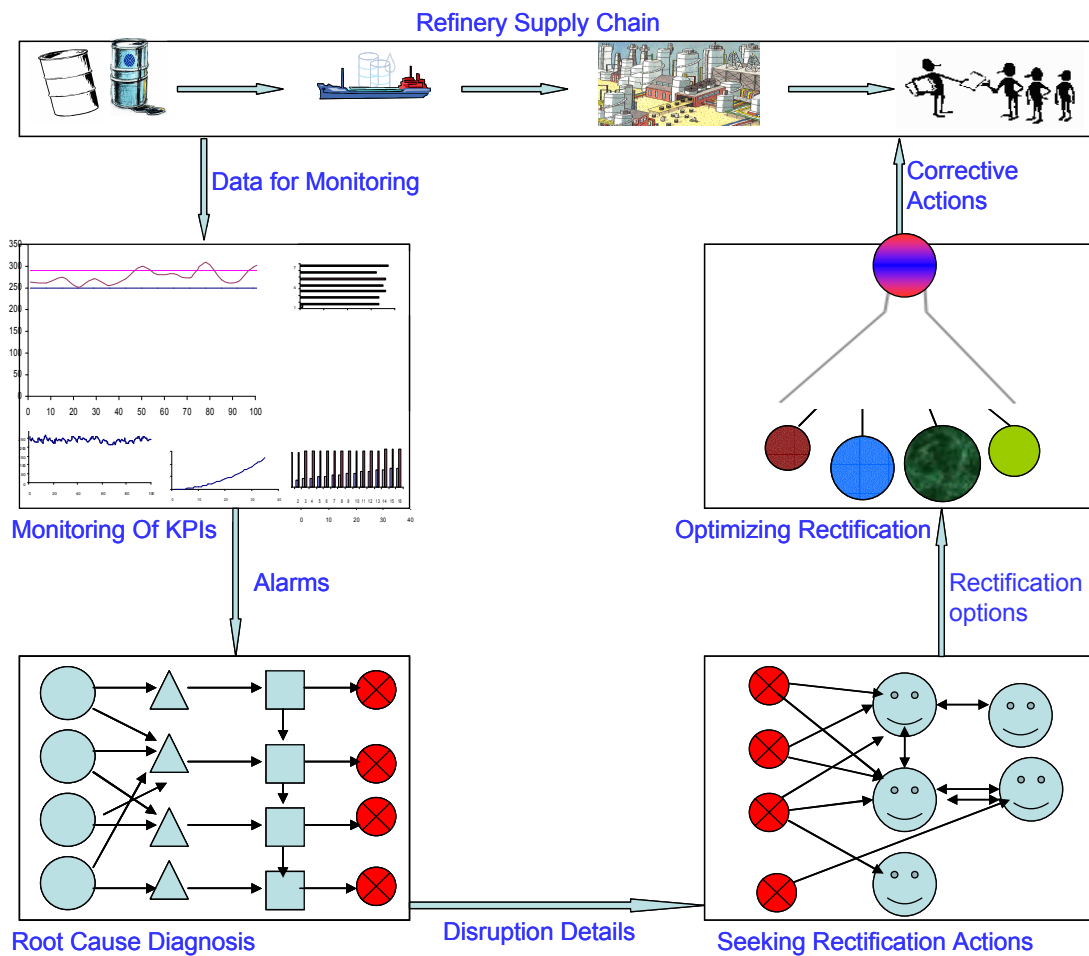


Figure 3.9: Feedback approach for managing disruptions in supply chain

Even though the two control methodologies work differently, but comparison can be made between the two. Table 3.1 summarizes the advantages and disadvantage between the two approaches. As both kinds of scenarios can happen in any supply chain, it would become difficult to achieve higher resilience in the supply chain by having only one

control approach for disruption management. Hence, we can conclude that both control methodologies are required to be implemented on supply chain to secure the supply chains from disruptions.

Table 3.1: Comparison of feedforward and feedback control approaches

S #	Feedforward	Feedback
1	Based on the monitoring of events and estimation of effects on supply chain	Based on the monitoring of the effects of the events in supply chain
2	Disruption detection is event driven and it is detected at the source itself	Detection of disruption is done by continuous monitoring of KPIs in the supply chain
3	The disruptive event is known and root cause diagnosis is not required	Root cause diagnosis is required and model-based or rule-based approach is used for root cause diagnosis
4	Criticality assessment is required to monitor the impact of all the unexpected events	Feedback approach can avoid criticality assessment of abnormal events
5	Disruption is detected before the event takes place, so higher resilience can be achieved.	Mostly disruption is detected after the abnormal event takes place, hence opportunity of rectification is reduced
6	The effects are estimated based on forecast, so inaccuracy in forecast can result into wrong decisions	The effects on supply chain are monitored, so the accuracy in disruption identification
7	Inefficient forecast can turn into over design of supply chain and non-optimal supply chain operation	Lower resilience in supply chains can result into weaker design of supply chain
8	Requires very informative supply chains with accurate modeling	Can be applied to well monitored supply chains
9	Rectification option seeking can be kicked-off at the point of disruption detection itself and can reduce time lag	Rectification option seeking is initiated by disruption management system

In this chapter, we covered the framework for managing disruption. In the next chapter, we explain in detail the implementation of its methodology. We also explain the modeling of supply chain, DMS, and information flow between them.

## **Chapter 4 Agent-based application on refinery supply chain**

The main components of the framework described in Chapter 3 are the SC entities, the SC model, and DMS. The critical thing for modeling this whole system is the modeling of information flow. As the supply chains are dynamic, distributed, and disparate, it is difficult to model the flow of information. In a supply chain, information storage can be distributed as well as centralized. When information is stored locally at multiple locations, we need a system that can pull distributed information for its use, as and when required. At the same time, when information is stored centrally, and is required at various locations, the model should be able to retrieve it from specific locations. Therefore, we need to design some specific properties in the model, which can accommodate abovementioned complexity in storing as well as retrieving information. Such information flow modeling can help in modeling activities, making decisions, simulating scenarios of supply chain, and finally the decision support for disruption management. Julka et al. (2002a) show that modeling of these kinds of systems can be done using an agent-based technique. This technique is also able to absorb all the aforementioned features of a supply chain in the model. Hence, we identify the agent-based approach as a suitable technique for modeling supply chains.

Julka et al. (2002a) propose three classes of agents in their framework, namely emulation agent, project agent, and query agent. In their paper, they define these agents, their roles, and domain of performance, and present some examples. To model resilient supply chains, we need one additional class of agents, which may be called the disruption management agents. This special class of agents can be a subclass of the project agent of Julka et al. (2002a). The subclasses of disruption management agents are as follows:

#### ***4.1 Disruption management agents***

Disruption management agents basically deal with the issues related to disruption management only. The assignments for these agents are based on the framework we described in the previous section. Hence, these agents require performing a few different types of tasks. Based on the works performed, we categorize this agent class under following subcategories:

1. Disruption Detector Agents
2. Disruption Diagnostic Agents
3. Rectification Strategy Seeker Agents
4. Optimal Strategy Selector Agents
5. Rectification Strategy Implementation Agents

All these agent classes cover the five steps of the framework and each agents class functions according to the responsibility allotted to them in their respective step. In our system we implement the work assigned to these agents in format of grafcet. The grafcet is composed of few threads and each thread has some embedded procedures inside itself, to perform certain set of activities. The Grafkets of DMS agents are provided in Figures 4.1 to 4.6.

We now present three case-studies to illustrate the ability of the proposed DMS to handle disruptions and to demonstrate its effectiveness in decision support. We select refinery supply chain as an example for this illustration and demonstration, as it is complex due to the following reasons:

1. More than five hundred different crudes are available for procurement from different parts of the world.

2. The crude can be transported by different ways, by land routes, by sea cargos, and by pipelines, which increases the complexity.
3. All refineries are different and complex.
4. Many operation units with different specifications.
5. Many products with different demands and qualities.
6. Demands of products are volatile and fluctuate quite frequently.

This shows that the refinery SC networks are very complex and vulnerable to disruptions. These networks can be exposed to disruptions in material flow, finance flow, and information flow. But for simplicity in understanding the disruption management, in this work we concentrate only on disruptions in material flow. The following types are the main disruptions that can happen in a refinery supply chain and can block material flow.

1. Changes in crude quality.
2. Disruptions in transportation makes crude arrive late at the refinery.
3. There is a fair chance that the essential equipment is not available.
4. Unscheduled shutdown in any unit.
5. Unavailability of facility to charge the crude to CDU (Crude Distillation Unit).
6. Abnormal demand fluctuation can force either shutdown or high throughput and cause disruption in the supply chain.



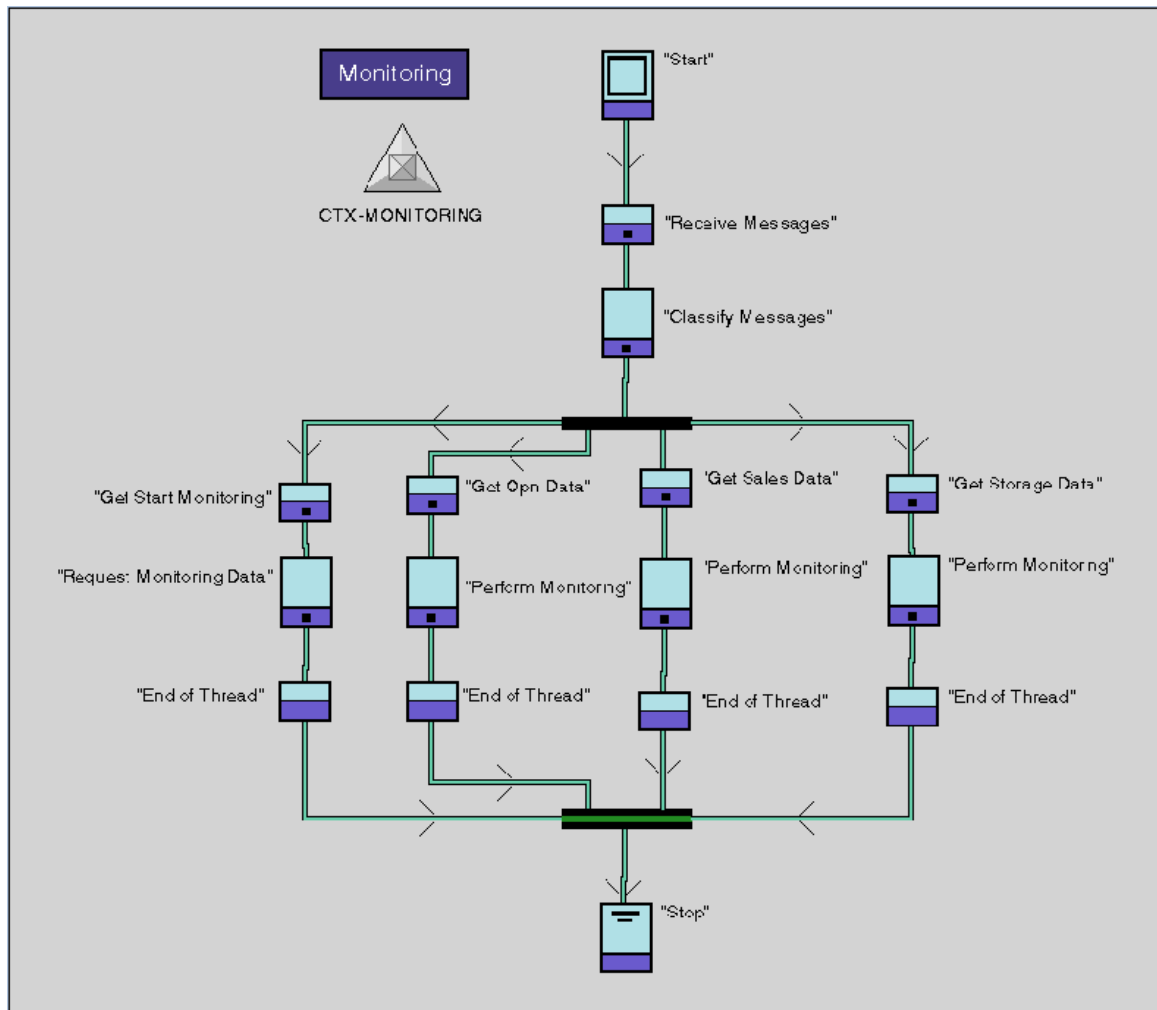


Figure 4.1: Grafcet of Monitoring Agent

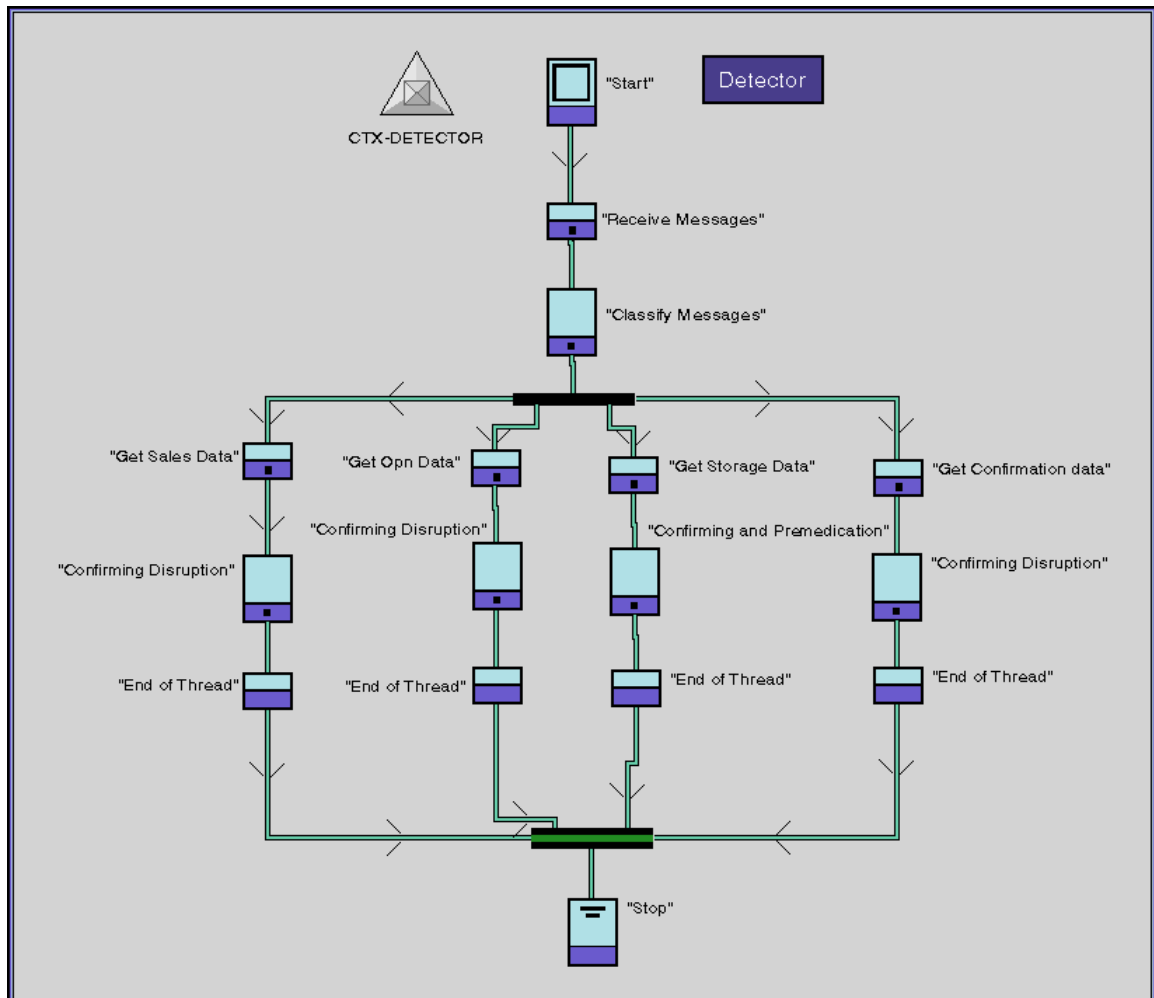


Figure 4.2: Grafcet of Detector Agent

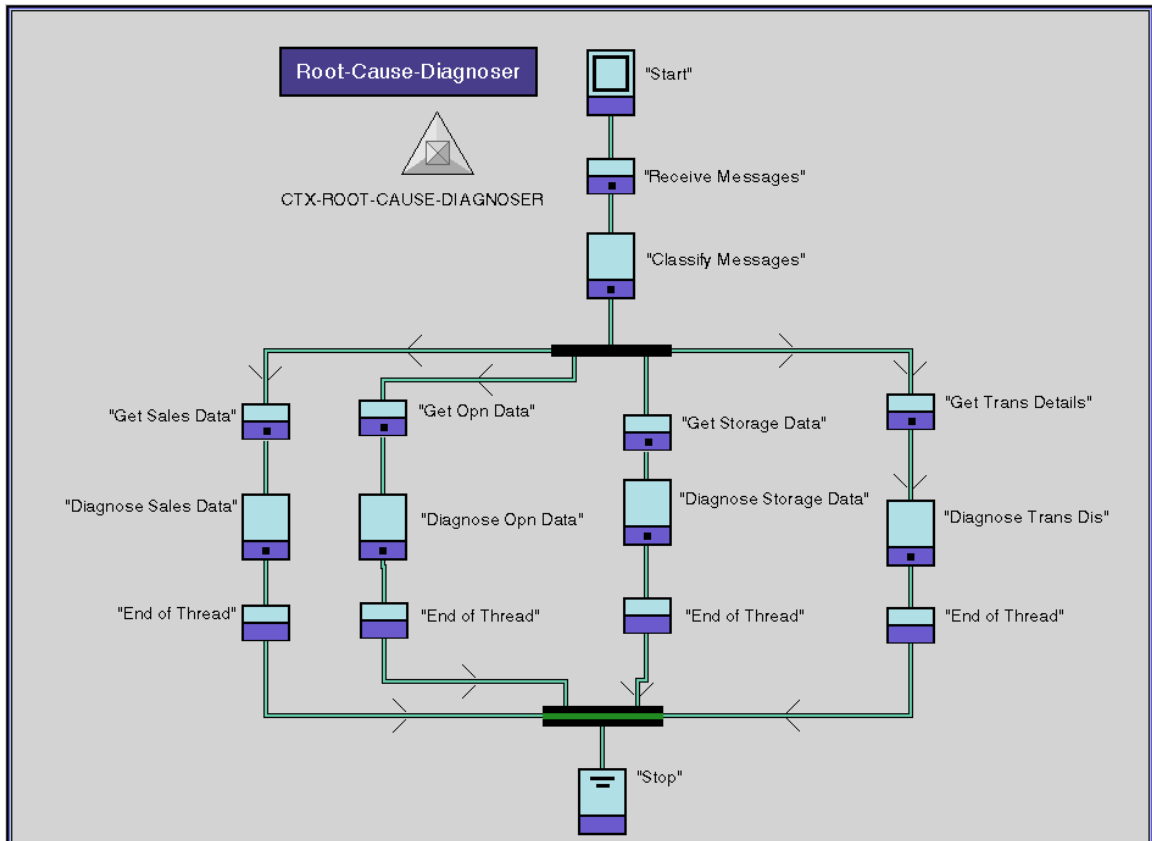


Figure 4.3: Graftet of Root Cause Diagnosis Agent

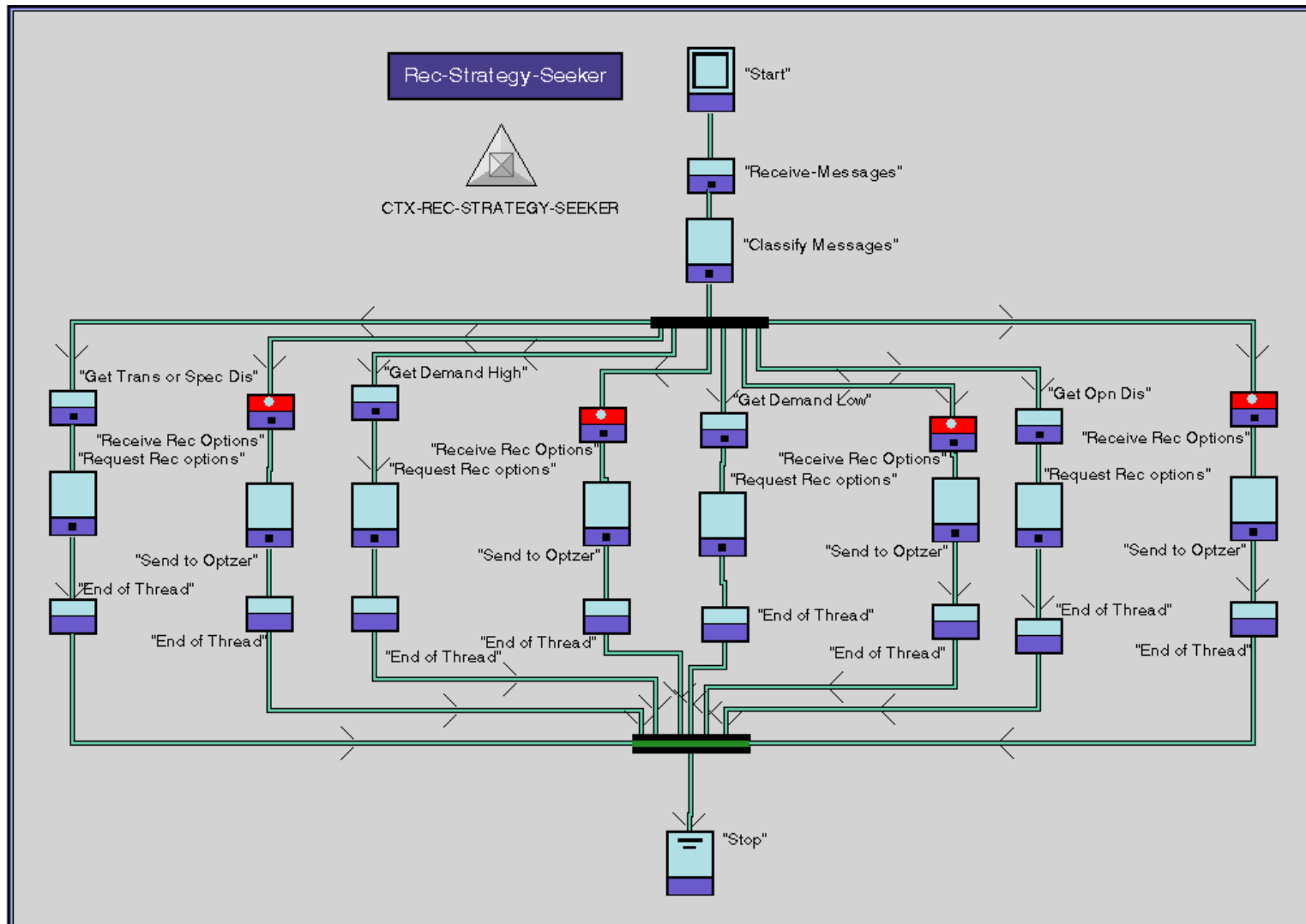


Figure 4.4: Grafcet of Rectification Strategy Seeker Agent

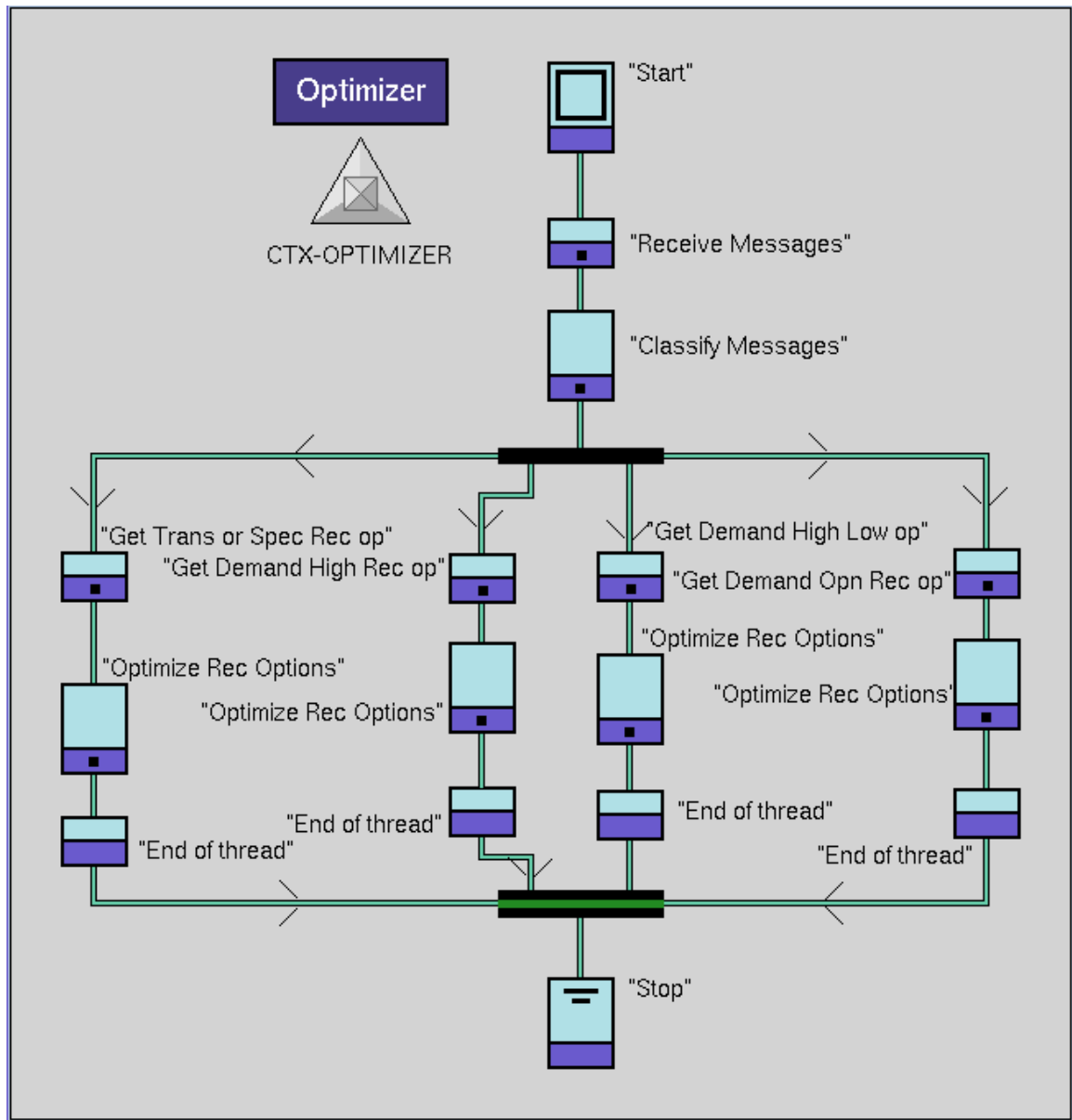


Figure 4.5: Grafcet of Rectification Strategy Optimizer Agent

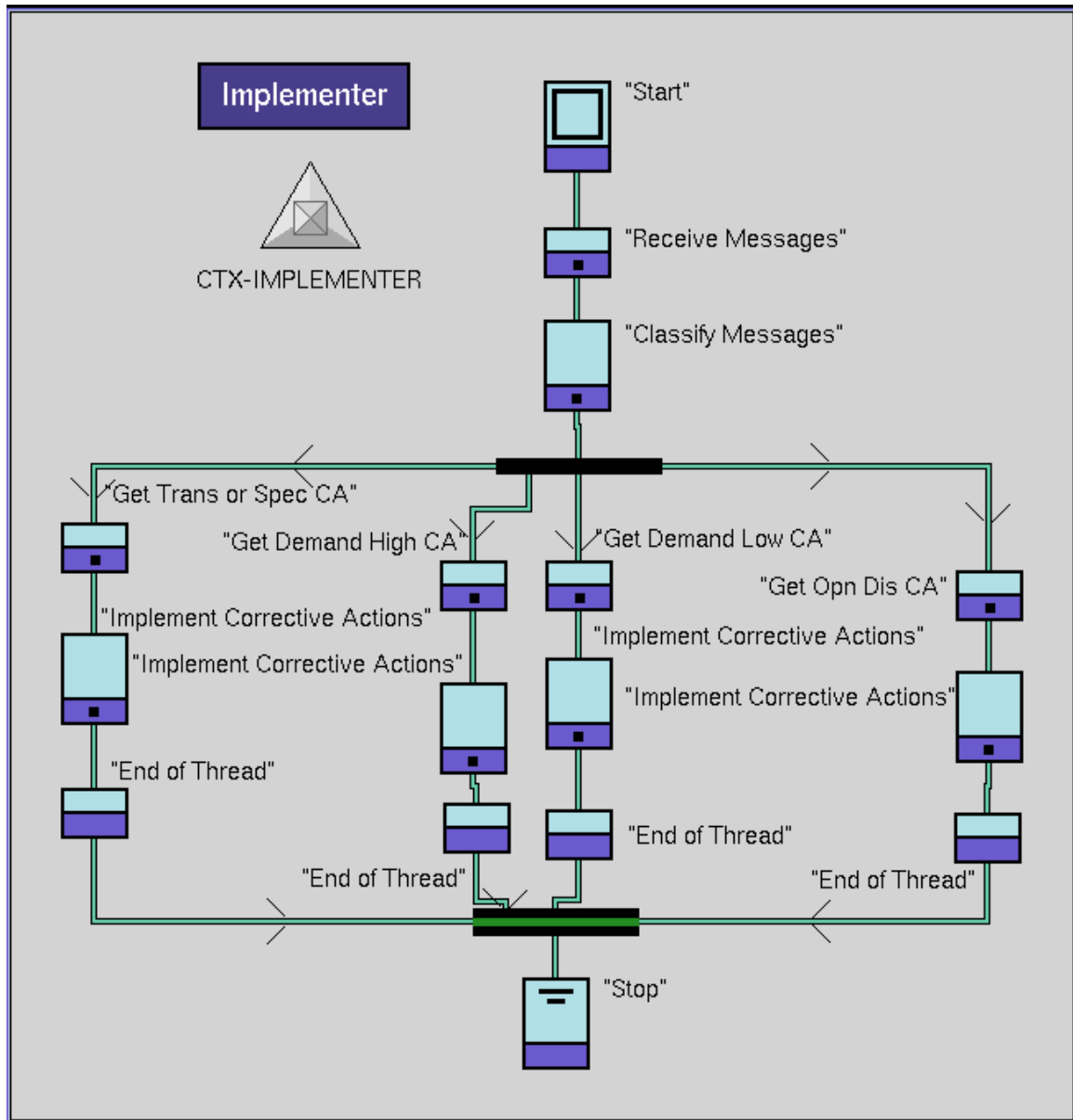


Figure 4.6: Grafcet of Rectification Strategy Implementer Agent

All the above listed scenarios can form a range of disruptions and it is cumbersome to perform study on all these scenarios, so we need to generalize these disruptions in a way to accommodate most of these scenarios. Hence, we select three scenarios of disruptions and present three case-studies; namely transportation disruption (crude shipment delay), urgent order, and unexpected order cancellation, parcel cancellation and facility operation disruption.

To understand the possible disruptions in a refinery supply chain, it is necessary to understand its business processes and its associated entities. In Figure 4.7, the entities related to supply chain are shown. In our studies we are considering the whole refinery supply chain from crude procurement to product distribution. The crude procurement, delivery, and storage process is described in detail by Julka et al. (2002b). From crude procurement to crude processing, the work flow for all departments is same as in Julka et al. (2002b). The workflow of crude procurement process is shown in Figure 4.8. Now, we extend the workflow of our model refinery to cover complete refinery supply chain. We extend the role of the departments as follows:

**Procurement:** In the present model refinery, the procurement department can provide rectification options to manage disruptions. This department has been given flexibility to buy the crude in emergency and negotiate on the amount of crude purchase. It is also responsible to coordinate with logistics department and arrange emergency transportation.

**Storage:** The storage department has been given responsibility to plan crude stock for future operations. It has to respond to other departments on the queries about the stock situation. It has been given ability to take actions on shipment delays, crude shortfalls due

to operational problems, and ullage shortfalls, by informing the department responsible for disruption management.

Sales: The sales department has been given responsibility to deal with the contingency with the sales of crude. During the fluctuations in the demands, this department can take necessary actions upon the requests from disruption management department. In case of product unavailability, it can postpone the demands of the products by changing the delivery date as well as the amount of product required. Whilst, when the demand of certain product is going low, it can set promotions on that product to recover the sale. It has also been given responsibility to sell the crude when there is surplus crude available in the tank farms.

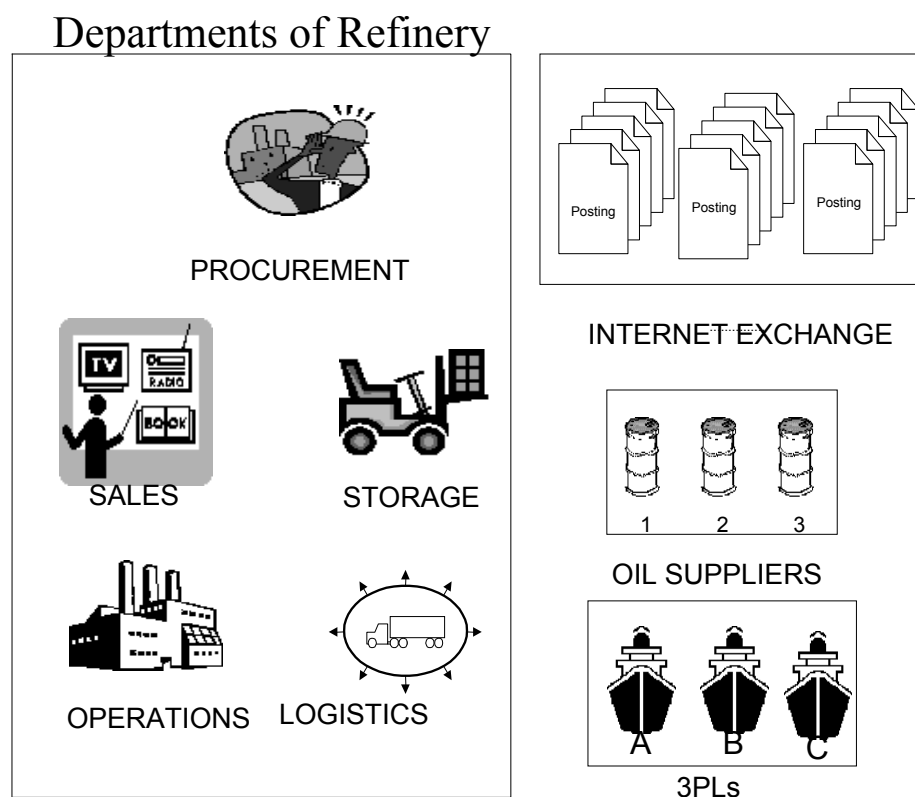


Figure 4.7: Entities associated with refinery supply chain



Operations: Besides deciding upon the crude quality, crude cut points and operating conditions of the units, this department takes necessary actions to avoid disruptions in supply chain. Though this department plans for its operations in advance, but to evade disruption, this department can change its operational plan like cuts, operating condition, throughput etc. It can also plan an emergency shutdown or can choose to operate the plant on maximum or minimum throughput. The model refinery has primary CDU (crude distillation unit) only, so operations department does the processing on straight run basis and keeps track of production according to the product demands given by sales department. This department also replies the queries of the disruption management department.

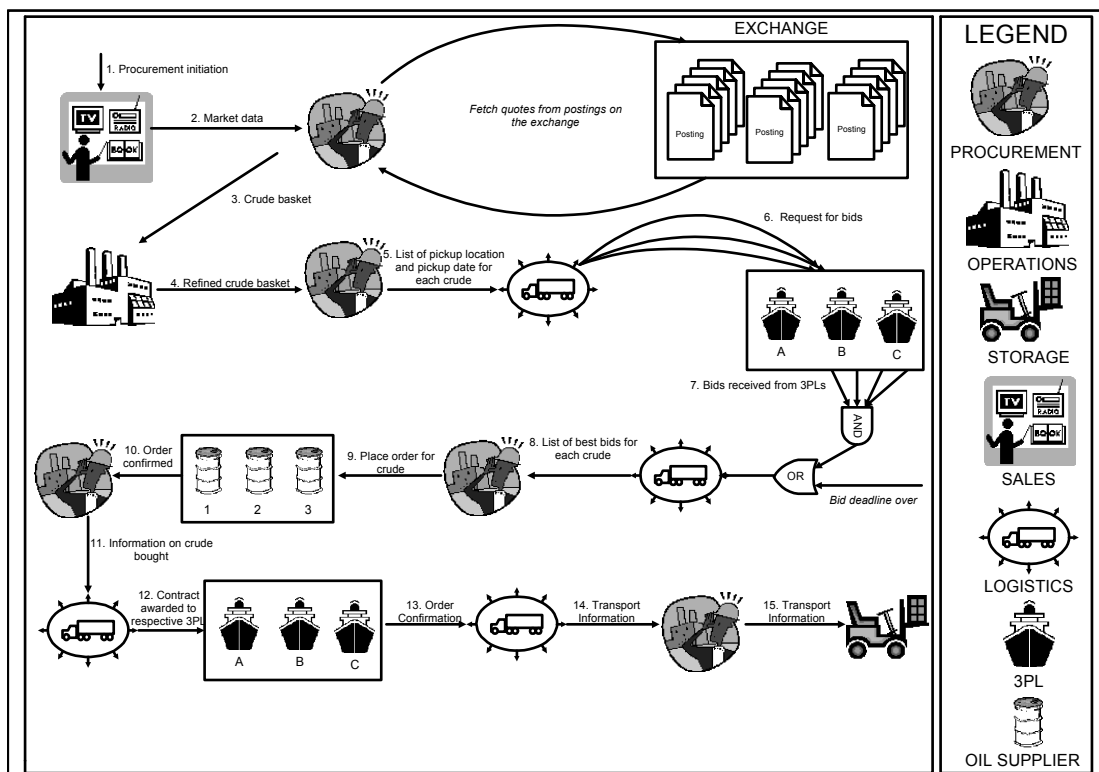


Figure 4.8: Workflow for refinery crude procurement process

Logistics: Logistics department maintains a list of selected 3PLs that can offer emergency transportation at higher tariff. The higher tariff can be justified as a trade-off to avoid the disruption, which can be taken as the cost of rectification. While selecting an emergency 3PL, it accounts for this cost of rectification.

The description of roles of entities in refinery supply chain is summarized in Table 4.1. Apart from the entities, to perform disruption management we need to have one more department in our model refinery called disruption management department in the refinery. The responsibilities of this department are as follows:

1. To monitor the performance of all the refinery departments.
2. Based on the critical deviations in the plans and functioning of these departments, it decides upon the possibility of a disruption in the refinery supply chain.
3. To confirm the deviations and to find the root cause of those deviations, it decides on the departments to contact, and the information required from those departments. Based on the received information, it reaches to the root cause of disruptions.
4. Upon finalizing the root cause, it finds out the departments that can help in rectifying or recovering from the disruption. It requests rectification options from those departments.
5. It receives the rectification options along with their costs and then it tries to select the best rectification strategy.
6. It orders to the respective refinery departments to execute corrective actions of the optimal strategy, and then it calculates the Resilience Index.

We use PRISMS (Petroleum Refinery Integrated Supply Chain Modeler and Simulator) developed by Julka et al. (2002; b) to model the refinery supply chain. The PRISMS corresponds to the SCMS of the framework. PRISMS comprises eight entities, (see Figure 4.7) five of these are refinery departments and three are external departments, and it does not model additional functionalities of the departments which we have listed above. Hence, we extend the functionality of the agents in PRISMS and give them capability to simulate disruptions in the supply chain. The disruption management department in the model refinery works as the Disruption Management System (DMS) in our framework. In PRISMS, we add a few more agents. These agents are from Disruption Management Agent class, and they perform different functions of the disruption management department of refinery. These agents are monitoring agent, disruption diagnostic agent, rectification strategy seeker agent, optimal strategy seeker agent and rectification strategy implementation agent.

For the case-studies, we first simulate the supply chain for normal (disruption-free) scenarios. Then, we introduce disruptions (this feature is user defined and we can choose the nature of disruption) by changing the parameters in PRISMS. Important parameters used in PRISMS and DMS are presented in Table 4.2. The system enables the supply chain to launch a disruption randomly. The DMS examines the effects of disruptions on the KPIs and performs disruption management. The three disruptions (transportation disruption, urgent order, and unexpected order cancellation) used for case-studies ultimately affect the crude stock. Transportation delays and urgent orders may cause crude shortfall, while unexpected orders may cause surplus crude in the storage. Hence, we define a common criterion for measuring the supply chain resiliency for our case-

studies based on the crude shortfall or crude excess. Thus, we define the Resilience Index as,

$$\text{Resilience Index} = \frac{\text{Amount of crude correction by DMS}}{\text{Amount of crude required to avoid disruption}}$$

Table 4.1: Description of entities and their roles in managing disruptions

<b>S No.</b>	<b>Entities</b>	<b>Functions and specifications</b>	<b>Rectifications offered</b>
<b>Refinery departments</b>			
1.	Procurement	<p>Buys only one crude in one cycle</p> <p>Depending upon requirement makes decision on procurement cycle frequency</p>	<p>Makes deals for emergency crude procurement</p> <p>Can change or freeze the order for procurement of crude</p>
2	Sales	<p>Deals with 7 products and forecasts their demands for future</p> <p>Can accept emergency order</p> <p>Makes a market survey at a frequency of 7 to 10 days</p>	<p>Can make fire sale</p> <p>Can postpone the demands</p>
3	Operations	<p>Takes the decision for the throughput</p> <p>Processes crude on straight run basis</p> <p>Prepares the production chart</p>	<p>Makes changes in throughput according to the changes in demands and the stock</p>
4	Storage	<p>Stores crude and releases it to operations department</p> <p>Plans general and safety stock and does regular stock keeping</p>	<p>Detects the future disruption by stock keeping for future</p> <p>Detects the ullage shortfall</p>
5	Logistics	<p>Communicates with 3PLs and places requests for bid</p> <p>Optimizes transportation cost, and selects the bid and awards the bid</p>	<p>Arranges the urgent logistics for emergency crude procurement</p>
<b>External entities</b>			
1	Petroleum Exchange	<p>Makes the information of crude sale with their specifications, rates and location and date of availability</p>	<p>Makes emergency crude available</p>
2	Oil Suppliers	<p>Posts crude sale information at the crude exchange</p> <p>Autonomously makes decision to sell the crude</p>	
3	3PLs	<p>Makes logistics available for transportation of crude</p> <p>Estimates the cost of transportation according to their rate and places the bid</p>	<p>Can offer emergency transportation</p>

Table 4.2: Parameters for the refinery supply chain in case-studies

Parameter	Value
<b>Procurement Department</b>	
Procurement cycle frequency	7 days
First day for product delivery	50 <sup>th</sup> day
Number of crude parcels	10
<b>Operations Department</b>	
Normal throughput	240 kbbbl/day
Maximum throughput	320 kbbbl/day
Minimum throughput	190 kbbbl/day
Processing time (from crude arrival to end product)	5 days
CDU efficiency	Variable
<b>Sales Department</b>	
Number of products	7
Price fluctuation factor in demand (based on last procurement cycle)	1%
Quantity fluctuation factor in demand (based on last procurement cycle)	3%
<b>Storage parameters</b>	
Buffer stock	Variable
Number of tanks for crude storage	4
Capacity of tanks	800 kbbbl

## ***4.2 Case-study 1: Transportation disruption***

Transportation disruptions are quite frequent in refinery supply chains and have significant impact on the performance such as stock-outs, etc. Oil shortage at the Sydney refinery (see Chapter 1) is one such example, which had huge consequences. Therefore, we consider delay in crude shipment as a disruption for demonstrating our DMS. We consider the following scenario:

The 3PL (Third Party Logistics) agent informs the storage agent that a crude shipment is delayed and gives a new arrival date. The storage department does the stock keeping for future. It keeps track of crude shipment details such as arrival date, 3PL identity, quantity to unload, etc. Everyday, at the start of the day, it sends the information about the available crude stock for a defined horizon to the monitoring agent in DMS. Based on the information from the operations agent, the monitoring agent continuously keeps track of the planned throughput. Upon receiving the information from the storage, it checks the crude inventory profile versus the planned throughput. If it foresees a stock out or severe deviation in the inventory profile that may affect the supply chain, it assumes a disturbance and informs the disruption diagnostic agent. The monitoring agent also computes the amount of crude required to meet the planned throughput and the date at which the crude is required, and it sends this information to the rectification strategy seeker agent. The disruption diagnostic agent does a rule-based analysis for the crude shortfall. It finds that possible reasons for the crude shortfall are: transportation delay, extreme decline in sales, or upset operations. It sends a message to the related agents, namely the storage, sales, and operation agents and enquires about the aforementioned possibilities. The agent finds that the root cause for this disruption is transportation delay

and informs the rectification strategy seeker agent. Rectification strategy seeker agent already has the information about crude specification, required amount, and the date of requirement. Then, this agent also applies a rule-based approach to find agents that can help in rectifying the disruption. Then, this agent performs following actions to solve the crude shortfall problem:

- 1) Sends the information to the procurement agent to check the availability of the required amount of appropriate crude.
- 2) Informs the operation agent and seeks the possibility of recovery by variations in throughput and operating conditions.
- 3) Informs the sales agent and seeks the details of deliveries that can be postponed.

After getting the rectification options from the above agents, this agent sends the collected options to the optimal strategy seeker agent. This agent decides the optimal rectification strategy depending upon the costs of the various rectification options versus the resilience offered by them. The goal of this agent is to achieve maximum Resilience Index for this disruption management scenario. Once the rectification strategy is optimized, the corrective actions are decided and then conveyed to the respective agents by the rectification strategy implementation agent. We tested our DMS on ten separate disruption scenarios and the results are presented in Table 4. We describe Run 1 here.

Run 1: The ship carrying the crude for procurement cycle P1 (1547 kbbl crude) was scheduled to arrive at the refinery on day 52. On day 42, the ship informs the refinery that it will arrive on day 58 instead of day 52. The storage agent updates its schedule for the ship arrival. The monitoring agent does stocking with planned throughput according to the following formulae.



$$S_{cn} = S_{c(n-1)} + SS_c - TP_n$$

Where,

$S_{cn}$  = stock of crude c on day n

$S_{c(n-1)}$  = stock of crude c on day (n - 1)

$SS_c$  = safety stock for crude c

$TP_n$  = Throughput on day n

Monitoring sends messages to DMS alarming about disruption if  $S_{cn} - TP_{\min} < 0$  where  $TP_{\min}$  = Minimum Throughput of refinery

In this run, the department anticipates a stock out situation on day 3 (stock at day 3 < minimum throughput of the refinery). Then, the department computes the amount of crude required to avoid the disruption based on following:

$$CCR = TP_m - S_{cm} + \sum_{x=m}^{x-q-1} TP_x$$

Where CCR = Crude correction required

m is the day of stock-out

q is the new arrival date

x is day such that  $q \leq x < m$

The monitoring agent finds that 873 kbbl of crude will be required to meet the planned production. On analyzing the rectification options by the associated agents, the rectification strategy seeker agent finds that the procurement department cannot offer any rectification, while the sales department can partially postpone the delivery of gasoline from day 57 to day 64. The reduction in the demand of gasoline can reduce the crude processing by 350 kbbl. As an optimal rectification option, the rectification strategy

implementation agent orders procurement agent to buy 600 kbbl of crude and it orders the sales agent to reschedule the delivery D1 and form new delivery orders D1a and D2a, where,

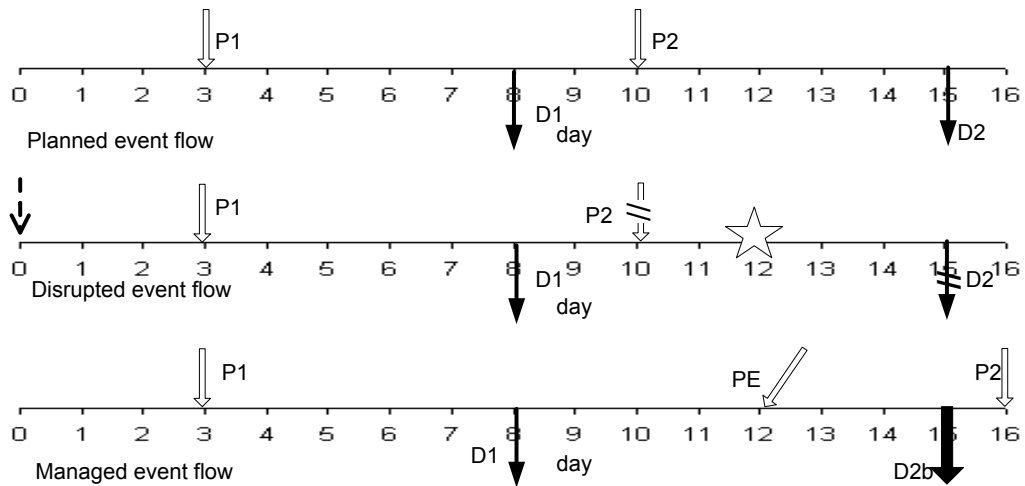
$$D1a = D1 - \text{the amount of gasoline delivery postponed}$$

$$D2a = D2 + \text{the amount of gasoline delivery postponed}$$

After the postponement of delivery, a change in the production schedule is also required, so the corrective actions are sent to the operations agent to change the throughput and operating conditions according to the new orders D1a and D2a. The flow of the events is given in Figure 4.9. In the figure the description of events is given with reference to date of detection. The event is detected on day 42, so day 42 is considered day 0 in the figure. Similarly, original ship arrival day, new ship arrival day, stock-out day and product delivery day become day 10, day 16, day 12 and day 15 respectively.

Table 4.3: Detailed problem data and results for case-study 1

S. #	Day					Crude on board (kbbl)	Crude rqd (kbbl)	Available rectification options			Optimal rectifications Proposed			$\epsilon$
	Detected	Ship arrival	Delayed ship arrival	Stock out	Delivery			Proc (kbbl)	Sales (kbbl)	Opn (kbbl)	Proc (kbbl)	Sales (kbbl)	Opn (kbbl)	
1	42	52	58	54	57	1547	873	600	350	969	600	273	273	1.00
2	46	52	58	53	57	1634	975	621	599	317	621	317	317	0.96
3	76	80	83	81	85	1747	295	172	364	107	172	107	107	0.95
4	126	129	135	131	134	1689	803	442	454	189	442	189	189	0.79
5	116	122	123	118	127	1600	900	283	769	121	283	121	121	0.45
6	110	115	116	108	113	1768	969	165	370	48	165	0	0	0.17
7	86	94	99	95	99	1492	728	915	813	500	728	0	0	1.00
8	64	66	72	68	71	1772	756	360	433	186	360	186	186	0.72
9	71	80	84	80	85	1660	727	957	862	408	727	0	0	1.00
10	85	87	91	89	92	1629	432	420	414	238	420	0	0	0.97



#### Case Study: Transportation Disruption

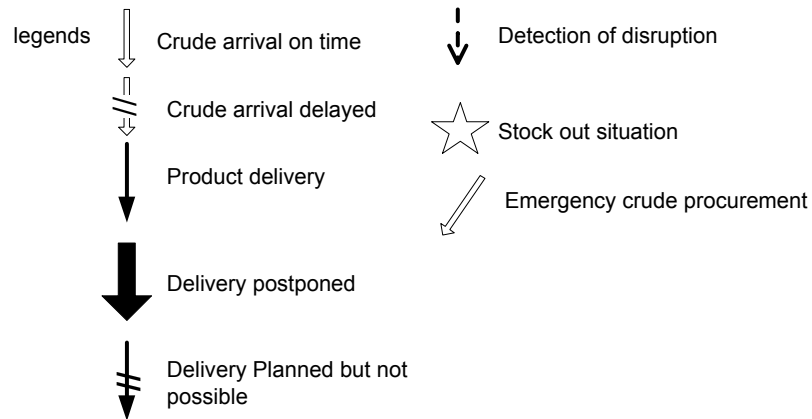


Figure 4.9: Event flow for case-study 1, Run1

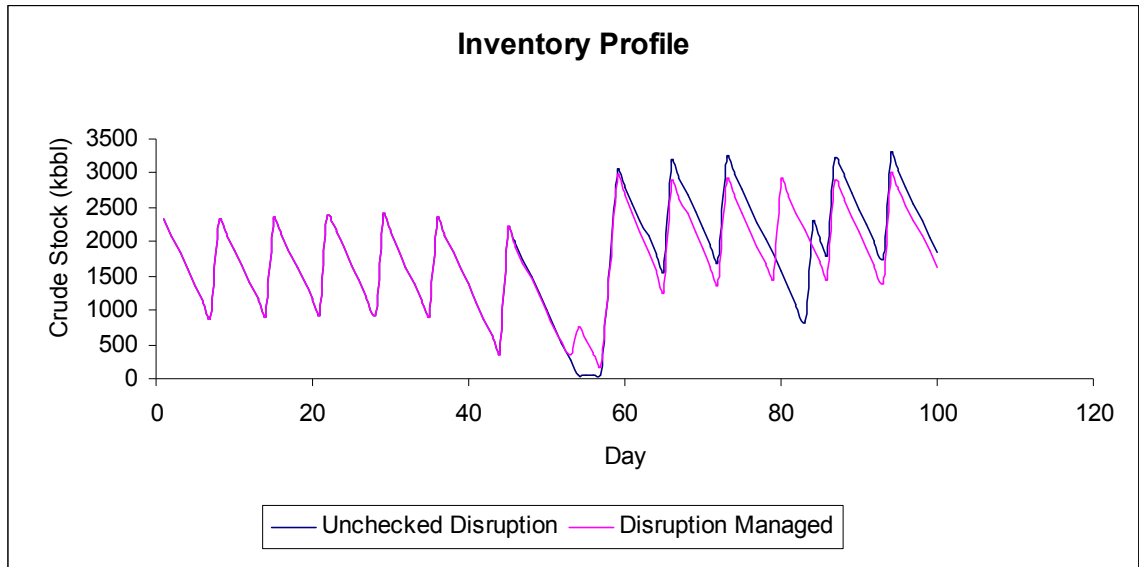


Figure 4.10: Inventory profile for case-study 1, Run1

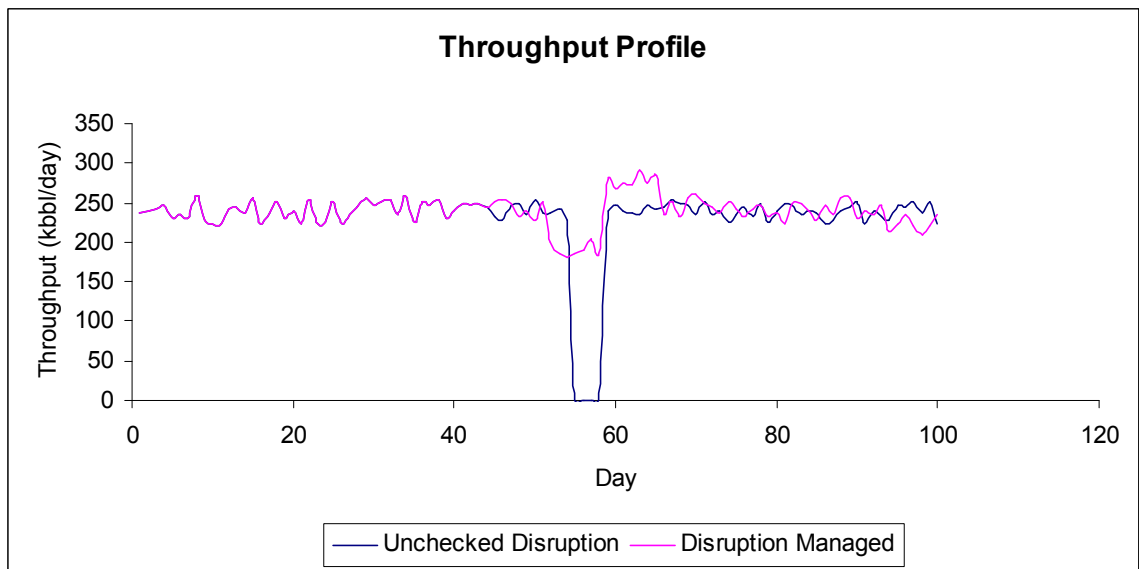


Figure 4.11: Throughput profile for case-study 1, Run1

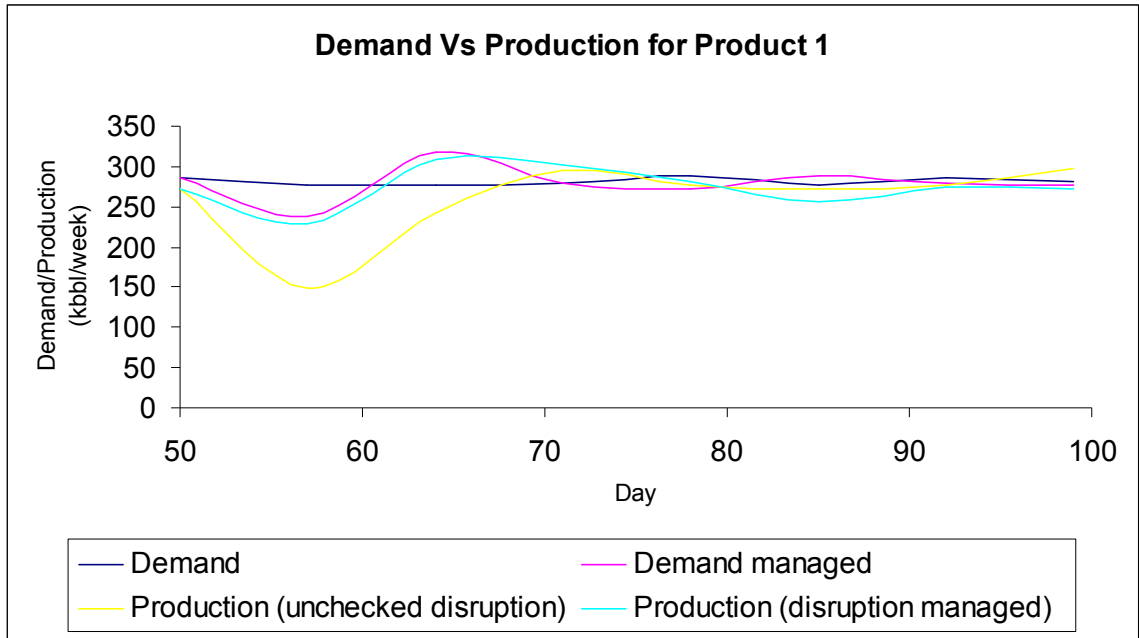


Figure 4.12: Demand vs. production for Product 1 for case-study 1, Run1

### 4.3 Case-study 2: Urgent order

In normal operations, production scheme is planned on the basis of estimated product demands by the sales department. The operations other than production, such as procurement, operations, storage, etc. are planned according to the production scheme. Any sudden change in the demand scenario may change the operations planning of the refinery. In case, there is inflexibility in operations, the scenario can turn into a disruption. In the next two case-studies, we evaluate the robustness of the refinery operations to sudden changes in demands under the scenarios of urgent order and unexpected order cancellation. For urgent order, we consider the following scenario:

The sales agent accepts an order for gasoline from the market. The delivery date for this order is such that the refinery cannot meet it under normal operation cycle. The monitoring agent gets demand information from the sales agent routinely. The monitoring agent notes this sudden change in the demand and classifies it as a disturbance in KPI.

Subsequently, it sends the information to the diagnostic agent. The rule-based procedure for diagnosis suggests that the storage, operations, and sales agents could be held responsible for this deviation. Queries are then sent to these agents to find the exact cause of this disruption. The diagnosis agent finds that storage and operations are performing normally. From the sales agent, it receives a reply about the acceptance of the urgent order; hence, it concludes that the root cause is the urgent order. After deciding the root cause, it passes the information to the rectification strategy seeker agent. The seeker agent has information about the agents who can help in rectifying the problem, so it does the following:

- 1) It sends the query to the procurement agent to get the amount of crude that the procurement agent can buy urgently to meet this order.
- 2) It asks the operation agent the maximum production of gasoline possible from changes in throughput and operating conditions.
- 3) It inquires from the sales agent if any other deliveries of gasoline could be postponed to meet this order.

This agent now passes these rectification options to the optimal strategy seeker agent. In case, the rectification option from one agent is enough for managing a disruption, the optimal strategy seeker agent still distributes the responsibility of disruption management among all the responsible agents for the following reasons:

If the sales agent tries to meet the delivery in the next delivery cycle, then many other deliveries can be missed.

If the operations agent tries to meet the deliveries by changing operating parameters, then critical and sudden changes in operations can put the operations at risk.

Emergency crude procurement is an expensive option and utilization of this option beyond a limit can affect the profitability of the business.

So, the rectification options seeking agent checks the rectification options and their costs and then decides the rectification strategy. Finally, the rectification strategy is sent to the respective agents by the rectification strategy implementation agent. Ten separate urgent order scenarios were tested and the results are presented in Table 5. We describe Run 1 here.

Run 1: The flow of events for this run is given in Figure 4.13, in which the description of events is based on date of detection. Hence, detection day, stock-out day and product delivery day become day 0, day 8 and day 13 respectively. According to the original schedule, delivery D1 was scheduled on day 99 and delivery D2 was scheduled on day 106. The crude shipments P2 and P3 were scheduled to arrive on days 94 and 101 respectively. On day 93, an urgent order is received by the sales agent. It is assumed that the crude is processed in a CDU and the products are formed in proportion to its cuts. Hence, the production is on straight run basis and on this basis:

$$P_{cp} = CC_{cp} \times TP_n$$

$P_{cp}$  is the production of product p from crude c

$CC_{cp}$  is crude cut of product p from crude c

$TP_n$  is throughput for day n

So change in demand  $\Delta D = \sum_p \Delta D_p$

$$\text{hence, } CCR = \sum_p \left( \frac{\Delta D_p}{CC_{cp}} \right) - SS_c$$



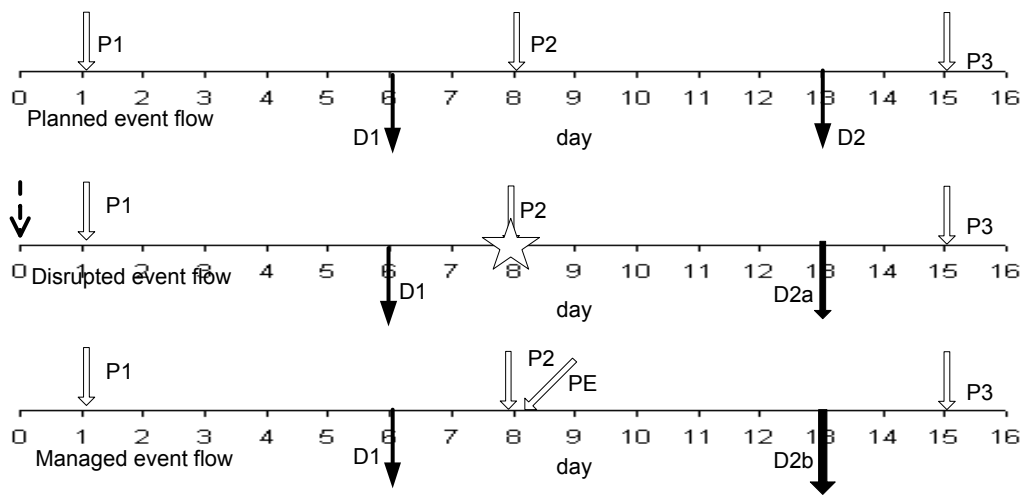
So, it was found that 1142 kbbl of crude would be required to meet the urgent order. In this run, the rectification proposed by the procurement, sales and operation were 600 kbbl, 350 kbbl and 620 kbbl respectively. The optimal corrective action was emergency procurement of 600 kbbl of crude. The emergency crude arrives at the refinery on day 101 and the urgent order is met successfully. The recovery index is 0.83.

Analyzing the ten runs, we observe that the efficiency to deal with the sudden orders is proportional to the time in hand for the urgent order fulfillment, and is inversely proportional to the volume of the urgent order.

The next case-study is also on demand fluctuation; where we consider low demand or order cancellation. As the rectification options to deal with this scenario are different from those for the previous scenario, this case-study is a good test for our framework.

Table 4.4: Detailed problem data and results for case-study 2

S. #	Date			Crude Rqd (kbbl)	Available Rectification Option			Optimal Rectifications			$\varepsilon$
	Detection	Stock- out	Delivery		Proc (kbbl)	Sales (kbbl)	Opn (kbbl)	Proc (kbbl)	Sales (kbbl)	Opn (kbbl)	
1	93	101	106	1142	600	350	620	600	350	350	0.83
2	64	74	78	860	785	856	810	785	75	75	1.00
3	71	79	85	1217	682	848	629	682	535	535	1.00
4	71	80	85	1021	720	824	385	720	301	301	1.00
5	85	93	99	1209	676	842	602	676	533	533	1.00
6	64	74	78	942	760	734	529	734	208	208	1.00
7	85	94	99	1034	690	795	702	690	344	344	1.00
8	85	96	99	678	834	849	867	678	0	0	1.00
9	64	75	78	510	624	590	613	510	0	0	1.00
10	71	80	85	1033	542	633	432	542	432	432	0.94



#### Case Study: Urgent Order

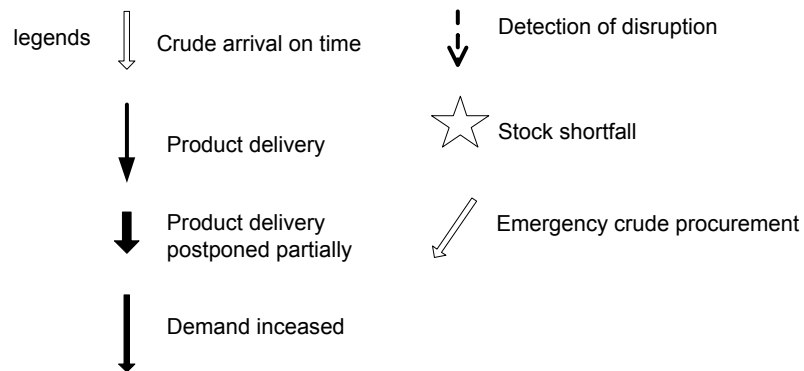


Figure 4.13: Event flow for case-study 2

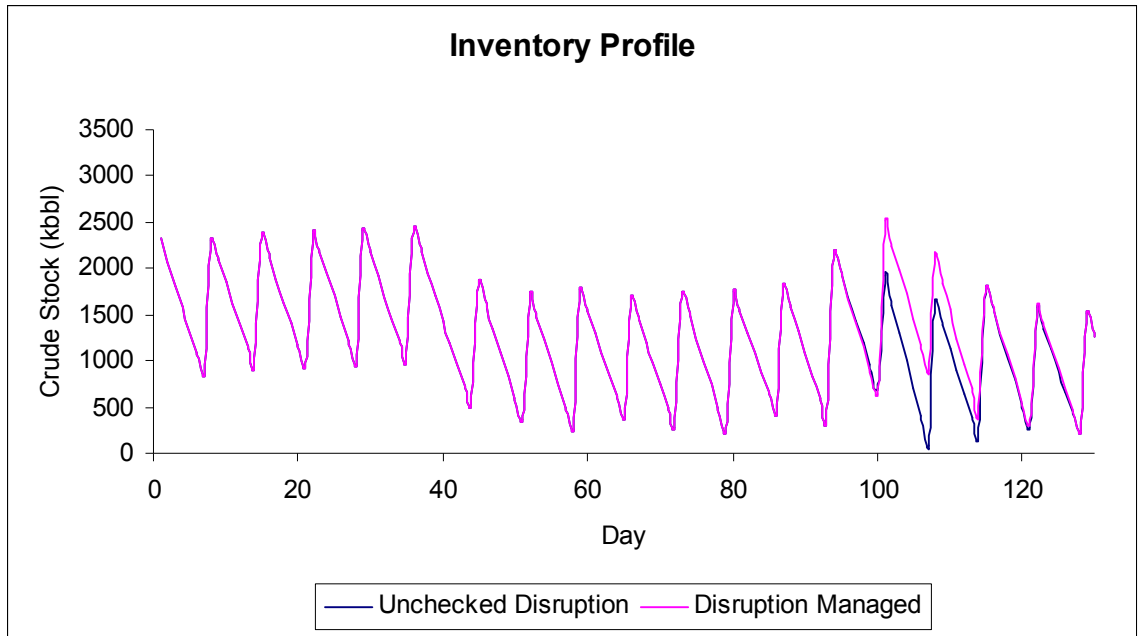


Figure 4.14: Inventory profile for case-study 2, Run1

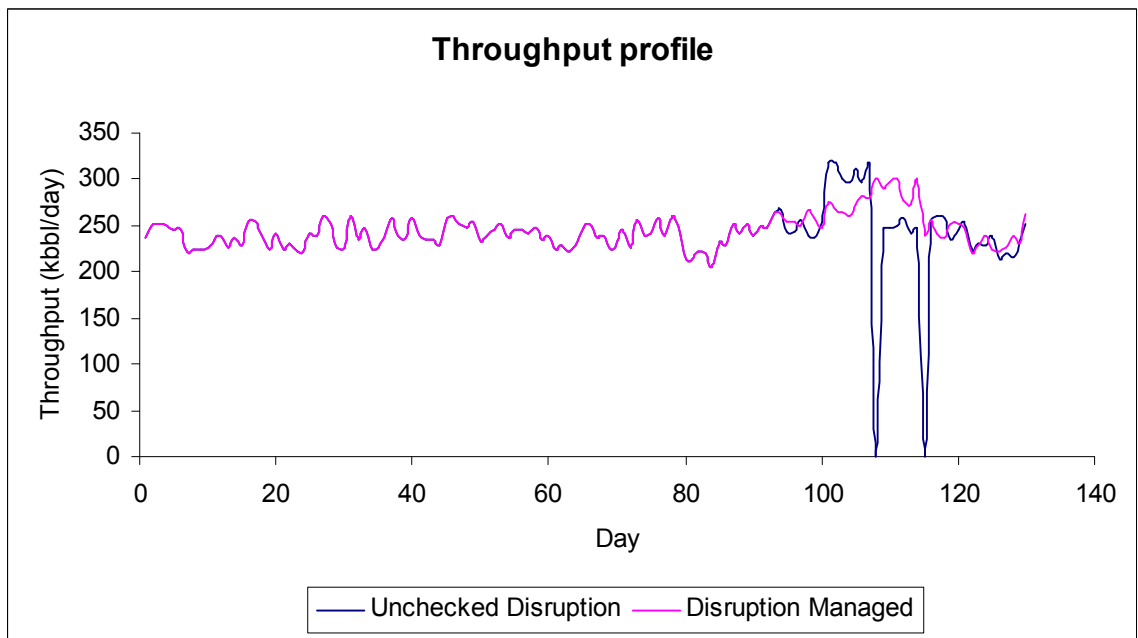


Figure 4.15: Throughput profile for case-study 2, Run1

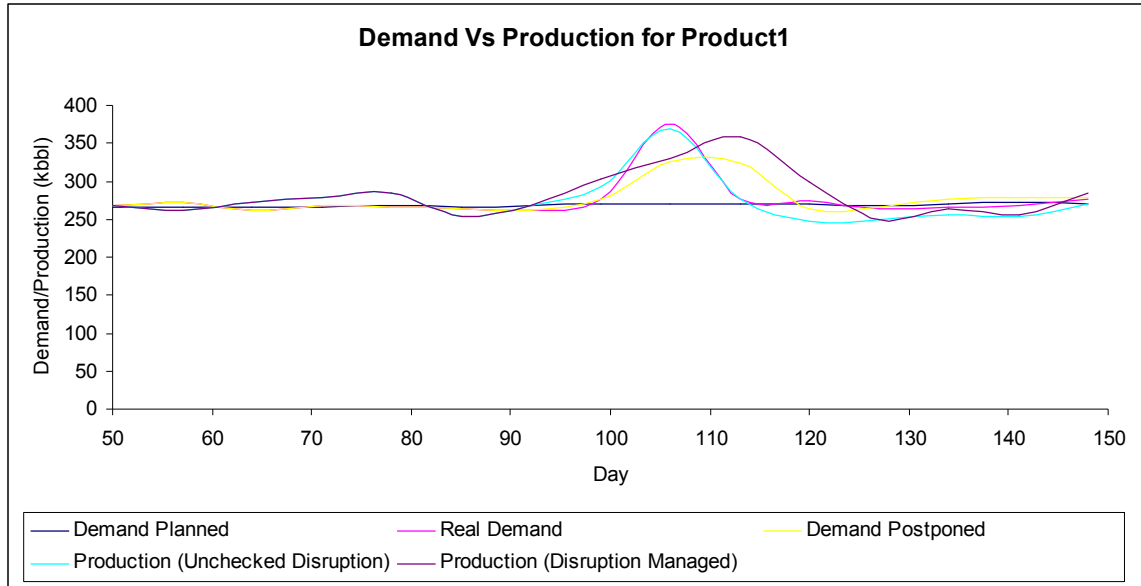


Figure 4.16: Demand vs. production for Product 1 for case-study 2, Run1

#### 4.4 Case-study 3: Unexpected order cancellation

If the sales department of a refinery faces a sudden order cancellation, the departments that are going to be affected mainly are the storage and operations. The cancellation causes changes in operating parameters, as a lower throughput requires changes in operating conditions. The reduction in throughput causes leftover crude in the stock, leading to reduced ullage in the storage tanks. The possible rectification options are: emergency sale of surplus crude, increment in product sales, and changes in the operating conditions to reduce the yield of product facing delivery cancellation. The following scenario is considered:

The work flows of the actions monitoring agent and diagnostic agent are the same as in the previous scenario. The monitoring agent catches the disruption and the diagnostic agent finds the root cause (sudden order cancellation). The rectification action seeker

agent finds that the operations and sales agents can assist in the rectification and takes the following actions:

- 1) It sends a query to the sales agent to get the amount of crude that it can sell urgently.
- 2) It asks the procurement agent about the possibility of partially or fully canceling crude procurement for the next cycle.
- 3) It inquires from the operations agent about the possibility of a change in product yield to meet the reduction in product demand.

Then, this agent passes the rectification options to the optimal strategy seeker agent. The rectification strategy is optimized as it was optimized in the previous scenario. Finally, the rectification strategy is implemented by the rectification strategy implementation agent. Again, ten separate scenarios were tested, and the results are presented in Table 6. Run 1 is as follows:

Run 1: The refinery was scheduled to deliver D1 and D2 on days 113 and 120 respectively. On day 107, a delivery for day 120 was cancelled. This generated an over supply of crude in the storage. If the crude supply is not stopped, or the crude is processed as per planned operation, the ullage shortfall could occur at day 114. The estimation of crude correction is done in similar fashion as in demand high scenario. In this scenario estimation of  $\Delta D$  is same as in previous scenario, but negative.

The crude correction required for this scenario is defined as

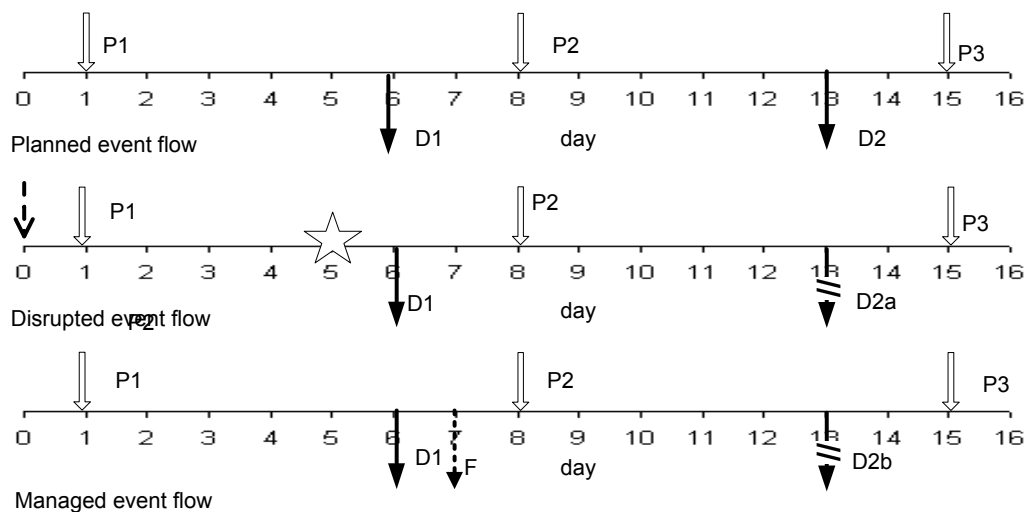
$$CCR = S_{c,\max} - S_{cn} + \sum_p \left( \frac{\Delta D_p}{CC_{cp}} \right)$$

where,  $S_{c,\max}$  is the maximum storage capacity for crude c

Table 4.5: Detailed problem data and results for case-study 3

S. #	Day			Crude Correction Rqd (kbbl)	Available Rectification Option			Optimal Rectifications			$\varepsilon$
	Detection	Ullage Shortfall	Delivery		Proc (kbbl)	Sales (kbbl)	Opn (kbbl)	Proc (kbbl)	Sales (kbbl)	Opn (kbbl)	
1	107	114	120	1352	500	350	490	500	350	350	0.63
2	71	80	85	1010	500	350	463	500	350	350	0.84
3	78	90	92	346	462	350	674	346	0	0	1.00
4	71	81	85	821	500	350	546	500	321	321	1.00
5	64	73	78	1019	500	350	470	500	350	350	0.83
6	92	101	106	1044	500	350	406	500	350	350	0.81
7	85	94	99	1074	500	350	457	500	350	350	0.79
8	85	95	99	845	300	350	498	300	350	350	0.77
9	64	75	78	509	300	350	502	300	209	209	1.00
10	57	66	71	1088	500	350	410	500	350	350	0.78

With this method the estimated oversupply was 1352 kbbl of crude. The procurement, sales and operations proposed rectification options of 500 kbbl, 350 kbbl and 490 kbbl of crude respectively. According to the optimal rectification, the procurement department was asked to sell 500 kbbl of crude, the sales department was asked to postpone deliveries for 350 kbbl of crude to avoid the ullage shortfall, the operations was told to reduce throughput equivalent to 350 kbbl of crude. The recovery index is 0.99. The event flow for this scenario is shown in Figure 4.17. As in case-study 1 and 2 the description in the figure is based on date of detection of disruption.



Case Study: Order Cancellation

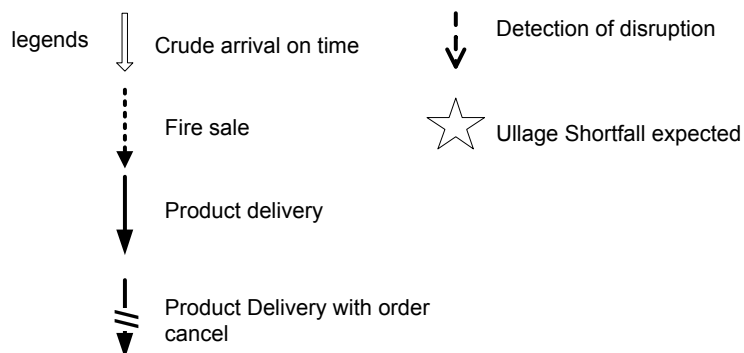


Figure 4.17: Event flow for case-study 3



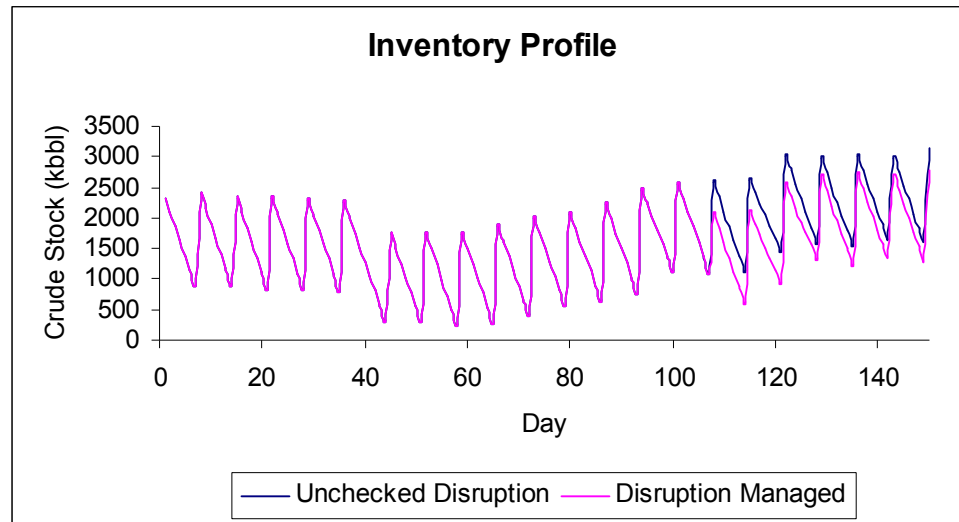


Figure 4.18: Inventory profile for case-study 3, Run1

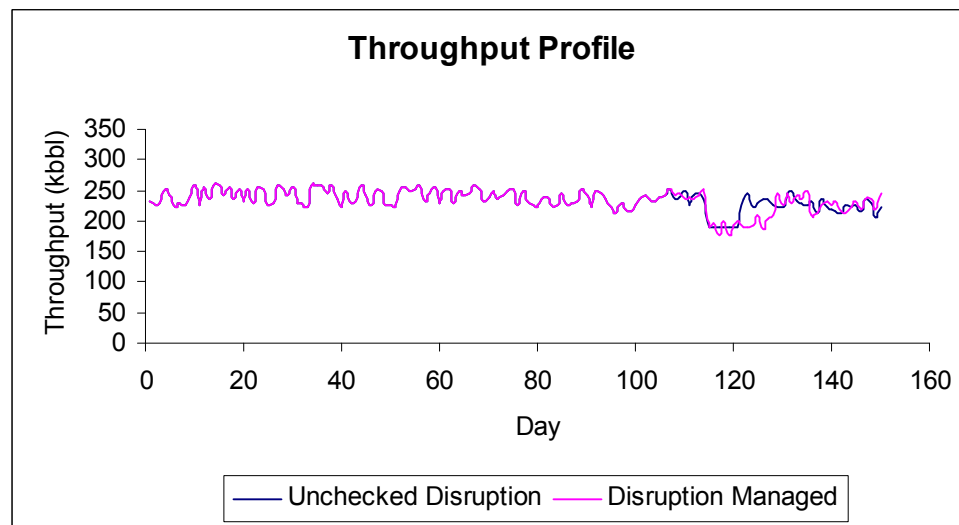


Figure 4.19: Throughput profile for case-study 3, Run1

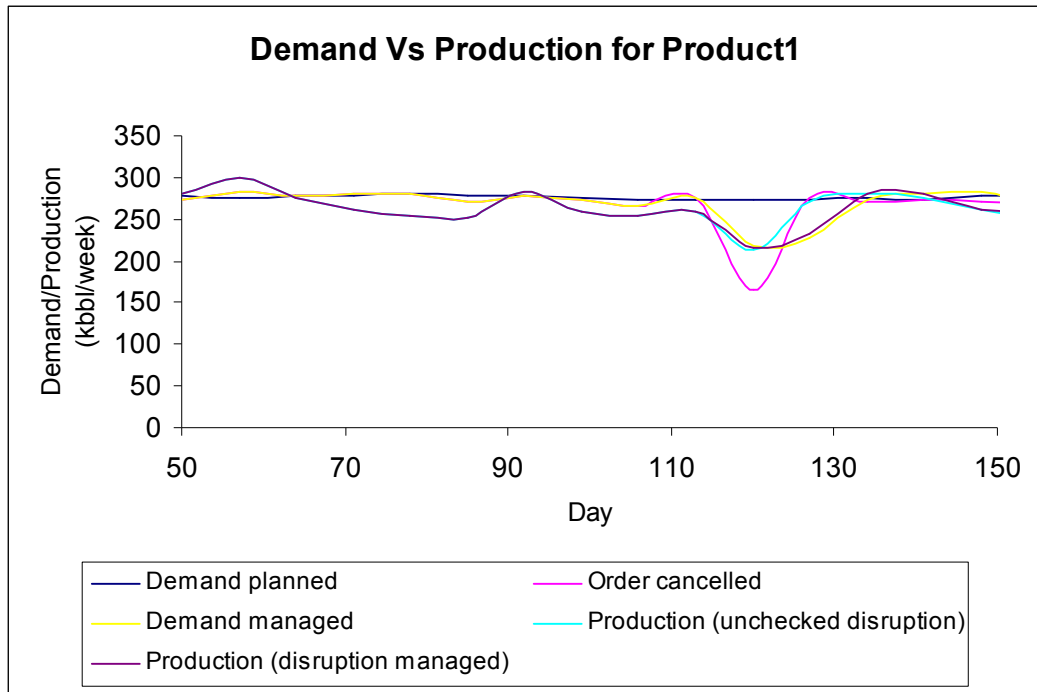


Figure 4.20: Demand vs. production for Product 1 for case-study 3, Run1

#### 4.5 Case-study 4: Crude Quality Disruption

Crude supplied to a refinery is checked for its quality, at the time of arrival of the crude cargo. In case the crude is found of de-rated quality, it is rejected and not unloaded from the ship. Normally, crude transportation cargos carry crude in parcels and each parcel is checked for quality. So, the crude can be partially or completely rejected based on its quality. Because most of the supply chains are planned for just-in-time scenarios, we identify that this sort of problem can lead to severe disruption in refinery supply chain. And in this scenario, the impacts of crude rejection are detected after the arrival of crude shipment, so the time to take corrective action is reduced. The situation can go even worse if the criticality assessment is not performed. We model this disruption in DMS without criticality assessment at the source of event. This disruption is based on feedback control methodology. The information about parcel rejection is not given to disruption

management system (DMS). DMS captures parcel rejection after root cause diagnosis and then proceeds for seeking rectification option.

We identify this scenario as potential case to illustrate the efficacy of feedback control approach. Hence, we study this problem in much detail and from the results we analyze impact of crude parcel rejection on various parameters of supply chain. The impact on the resilience of the supply chain is shown in Figure 4.21. We consider 10 parcels of crude to be supplied to refinery, and then we set a probability of rejection on each parcel. In certain delivery only some parcels are rejected which leads to disruption, the DMS takes corrective action to achieve resilience. Safety stock which is maintained for emergency situations is changed in every run. The impact of the level of safety stock is analyzed and it is found that resilience index varies proportionally with the safety stock level (see Figure 4.22). The ups and downs in the figures reflect the effect of the random factor used for proposing the corrective actions.

#### *4.5.1 Crude Quality Disruption Index (CQDI)*

As the crude quality of the shipment gets worse the impact on supply chain grows. Impact on the resilience can also be explained with variation in safety stock level. The resilience index (RI) shows combined impact of these two factors. So from the results it is difficult to illustrate the impact of one of the parameters. Hence, we define a number, Crude Quality Disruption Index (CQDI) which can demonstrate the combined impact of both the parameters.

$$\text{Crude Quality Disruption Index (CQDI)} = \frac{\text{Number of parcels accepted}}{\text{Number of parcels being transported}} \times \text{Safety stock}$$

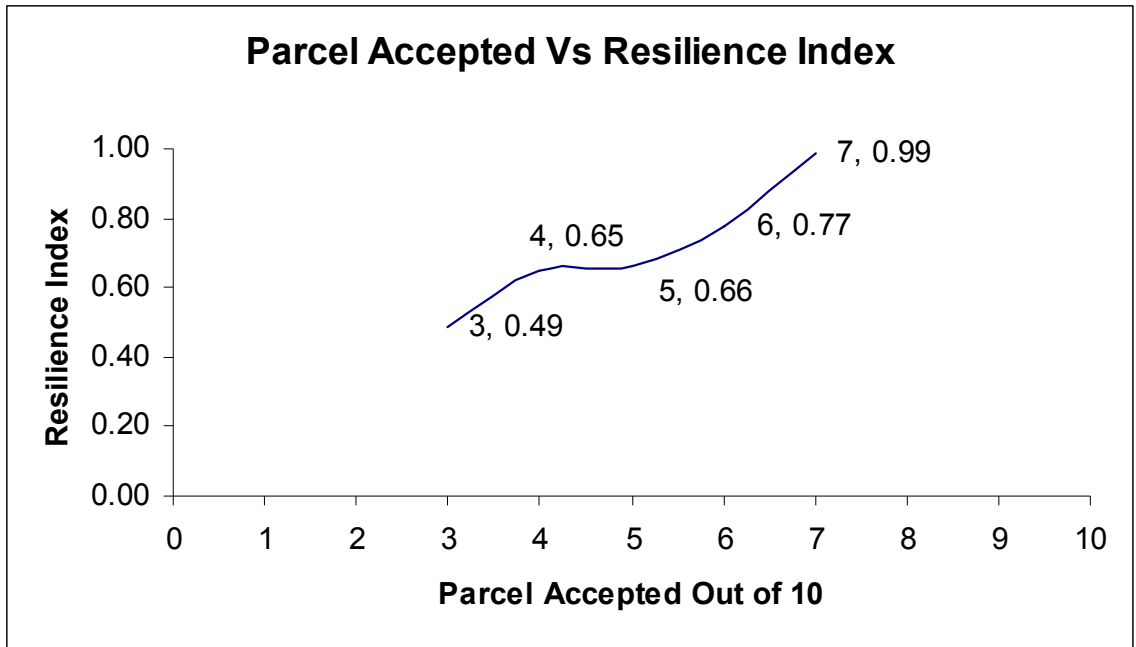


Figure 4.21: Impact of crude parcel rejection on resilience of supply chain

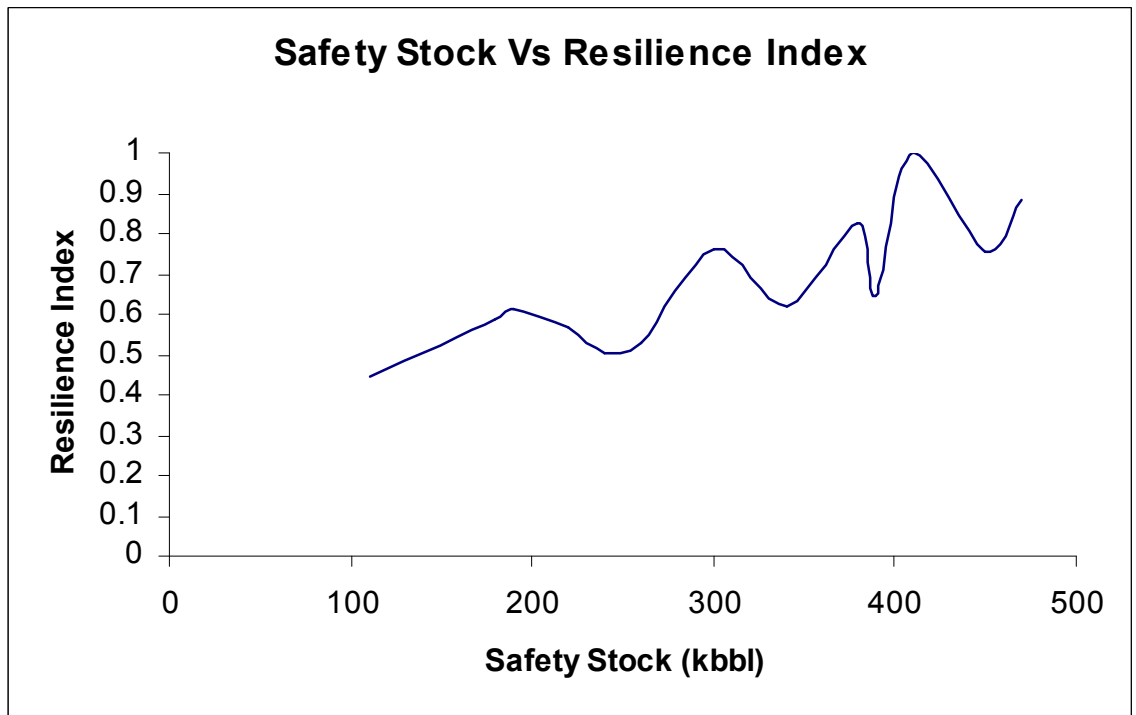


Figure 4.22: Impact of crude safety stock level on resilience for 50% crude rejection

Figure 4.23 shows that with the increment in CQDI the resilience of the supply chain also increases. PRISMS and DMS use a few random factors in managing disruptions, so a little randomness is also reflected in the results and makes the graph unclear. Hence moving average method is used for plotting the graph to make the curve smooth. CQDI can be used in for estimating minimum amount of safety stock level from a given possibility of crude rejection. For a desired resilience index the value of CQDI can be estimated from this graph and for a given possibility of crude rejection, using the given formulae for CQDI, we can back calculate the safety stock level required.

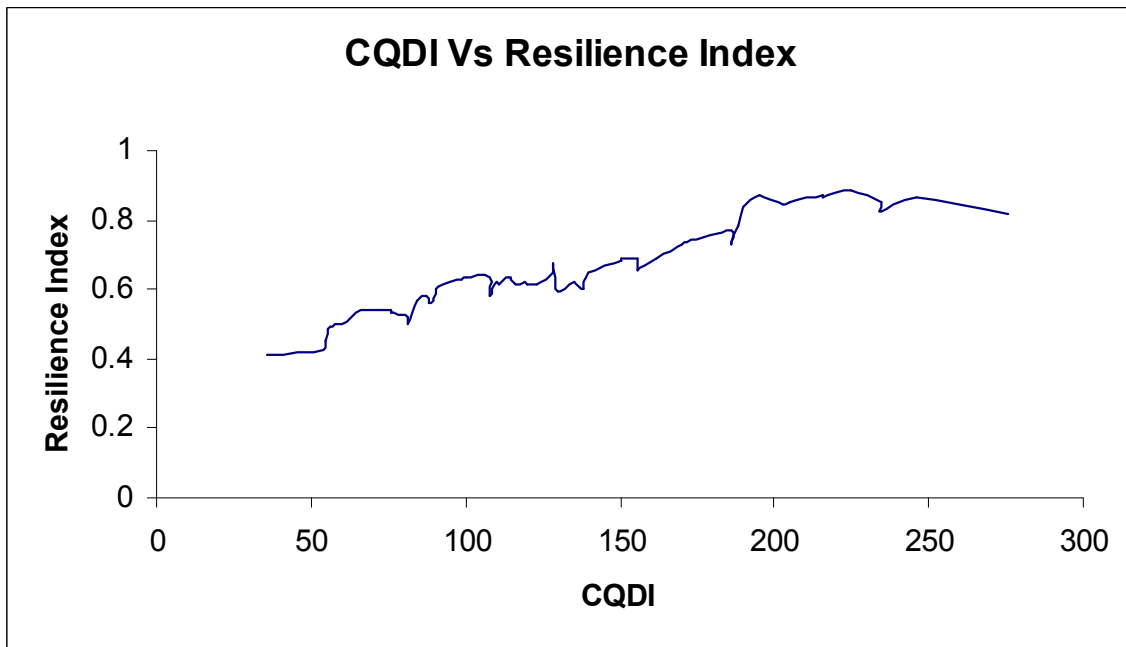


Figure 4.23: Crude Quality Disruption Index vs. resilience of supply chain

The event flow for this disruption is similar to that of transportation disruption. The 3PL agent informs the Storage agent that crude shipment has arrived. The storage agents checks the quality of the crude and crude quality is found de-rated and a certain number of parcels are found unacceptable for processing. The storage department unloads the acceptable parcels of crude. Unlike transportation disruption, storage agent does not

perform stocking in this case. Hence, storage agent is unaware of the criticality of the rejection of parcels. The monitoring agent retrieves information from storage agent about the stock situation and does the stocking for a defined number of days. If it foresees a stock out or severe deviation in the inventory, it notes the disturbance and informs the disruption diagnostic agent. After the diagnosis of root cause, the threads for crude specification disruptions are similar to those for transportation disruption. Similar to transportation disruption case-study, rectification strategy seeker agent computes the amount of crude required meeting the planned throughput, date of crude requirement and it sends this information for seeking rectification options. Detailed explanation of these threads can be found in the description of case-study 1. We had 57 runs for this case study and the results are presented in Table 4.6, Table 4.7, Table 4.8. We describe Run 1 here.

Run 1: The ship carrying 10 parcels of crude (quantity: 1529 kbbl) arrives at the refinery on day 94. Upon crude quality check it found that 7 of the parcels are not acceptable for processing in refinery and those parcels are not unloaded. Hence only 459 kbbl of crude is unloaded. On day 95, the monitoring agent does stocking with planned throughput according to the following formulae.

$$S_{cn} = S_{c(n-1)} + SS_c - TP_n$$

where,

$S_{cn}$  = stock of crude c on day n

$S_{c(n-1)}$  = stock of crude c on day (n - 1)

$SS_c$  = safety stock for crude c

$TP_n$  = Throughput on day n

Monitoring Agent sends messages to diagnostic agent regarding disruption if  $S_{cn} - TP_{\min} < 0$  where  $TP_{\min}$  = Minimum Throughput of refinery

The calculated date for stock out is 98 and the amount of crude required to avoid disruption is based on following formulae.

$$CCR = TP_m - S_{cm} + \sum_{x=m}^{x=q-1} TP_x$$

where CCR = Crude correction required

m is the day of stock-out

q is the new arrival date

x is day, such that  $q \leq x < m$

The monitoring agent finds that 891 kbbl of crude will be required to meet the planned production. The rectifications offered by procurement agent, sales agent and operations agent are 228 kbbl, 254 kbbl and 150 kbbl respectively. The optimal rectification strategy suggests that procurement should buy 228 kbbl of crude and sales should postpone the product demand equivalent to 254 kbbl of crude processing and operations shall change the throughput and process 150 kbbl of additional crude. The resilience achieved is 042.

Table 4.6: Detailed problem data and results for case-study 4 (Part I)

S. #	Day				Crude				Available Rectification Option (kbbl)			Optimal Rectifications (kbbl)			Safety Stock (kbbl)	$\varepsilon$
	Crude Recd	Detected	Stock- out	Delivery	On Board	Rcd	Parcel rejtd	Rqd	Proc	Sales	Opn	Proc	Sales	Opn		
1	94	95	98	99	1529	459	7	891	228	254	150	228	150	150	180	0.42
2	66	67	70	71	1770	531	7	787	281	254	138	281	138	138	370	0.53
3	73	74	77	78	1601	480	7	760	310	223	133	310	133	133	330	0.58
4	66	68	71	71	1777	533	7	700	305	192	116	305	116	116	220	0.60
5	94	96	99	99	1615	485	7	808	254	174	159	254	159	159	450	0.51
6	73	75	78	78	1710	513	7	604	308	183	131	308	131	131	410	0.73
7	94	94	96	99	1522	457	7	1027	172	303	101	172	101	101	500	0.27
8	73	73	76	78	1799	540	7	847	212	292	183	212	183	183	270	0.47
9	66	66	69	71	1702	511	7	828	252	284	144	252	144	144	290	0.48
10	101	101	104	106	1521	456	7	904	262	312	113	262	113	113	120	0.41
11	66	67	70	71	1715	514	7	898	254	241	121	254	121	121	250	0.42
12	80	82	85	85	1657	497	7	751	223	185	158	223	158	158	200	0.51
13	59	60	63	64	1657	497	7	947	257	232	139	257	139	139	270	0.42
14	66	68	71	71	1536	614	6	740	262	174	162	262	162	162	320	0.57
15	59	61	64	64	1604	642	6	572	303	178	162	303	162	162	470	0.81
16	66	68	71	71	1610	644	6	578	296	196	149	296	149	149	270	0.77
17	73	75	78	78	1643	657	6	729	262	186	164	262	164	164	320	0.58
18	80	81	84	85	1760	704	6	851	295	212	164	295	164	164	250	0.54
19	66	67	70	71	1706	682	6	805	270	201	166	270	166	166	390	0.54
20	80	81	84	85	1806	723	6	858	219	231	197	219	197	197	190	0.48
21	80	81	84	85	1729	692	6	803	262	230	132	262	132	132	220	0.49
22	73	74	77	78	1721	689	6	960	264	251	214	264	214	214	290	0.50
23	73	74	77	78	1640	656	6	880	262	237	153	262	153	153	140	0.47
24	66	67	70	71	1731	692	6	872	275	237	134	275	134	134	430	0.47
25	66	68	71	71	1587	635	6	562	300	177	124	300	124	124	350	0.75



Table 4.7: Detailed problem data and results for case-study 4 (Part II)

S. #	Day				Crude				Available Rectification Option (kbbbl)			Optimal Rectifications (kbbbl)			Safety Stock (kbbbl)	$\varepsilon$
	Crude Recd	Detected	Stock- out	Delivery	On Board	Rcd	Parcel rejtd	Rqd	Proc	Sales	Opn	Proc	Sales	Opn		
26	59	61	64	64	1770	708	6	559	261	187	168	261	168	168	190	0.77
27	73	74	77	78	1635	818	5	955	279	247	199	279	199	199	240	0.50
28	80	82	85	85	1644	822	5	625	262	205	141	262	141	141	390	0.64
29	66	68	71	71	1694	847	5	639	258	191	116	258	116	116	180	0.59
30	80	81	84	85	1755	878	5	938	278	239	141	278	141	141	110	0.45
31	73	75	78	78	1806	903	5	761	290	177	183	290	177	177	190	0.61
32	80	80	83	85	1704	852	5	783	262	306	152	262	152	152	260	0.53
33	87	89	92	92	1680	840	5	589	299	184	150	299	150	150	300	0.76
34	108	111	114	120	1711	855	5	438	249	115	112	249	112	112	380	0.82
35	115	118	121	127	1409	704	5	316	223	121	106	223	93	93	410	1.00
36	59	61	64	64	1789	894	5	563	261	169	194	261	169	169	470	0.76
37	94	97	100	106	1779	890	5	520	259	135	176	259	135	135	450	0.76
38	66	69	72	78	1733	867	5	357	262	124	139	262	95	95	470	1.00
39	101	103	106	106	1685	842	5	632	230	179	161	230	161	161	340	0.62
40	59	61	64	64	1633	816	5	749	257	167	187	257	167	167	220	0.57
41	101	104	107	113	1529	917	4	377	234	105	149	234	105	105	230	0.90
42	108	110	113	113	1594	956	4	509	219	172	105	219	105	105	310	0.64
43	59	62	65	71	1671	1002	4	354	261	127	123	261	93	93	310	1.00
44	66	68	71	71	1651	990	4	543	251	170	176	251	170	170	410	0.78
45	115	118	121	127	1335	801	4	504	248	119	168	248	119	119	120	0.73
46	108	109	112	113	1567	940	4	974	217	235	184	217	184	184	140	0.41
47	73	75	78	78	1652	991	4	578	262	191	135	262	135	135	310	0.69
48	59	61	64	64	1783	1070	4	746	261	183	174	261	174	174	190	0.58
49	108	111	114	120	1764	1058	4	370	216	109	161	216	109	109	270	0.88
50	115	116	119	120	1652	991	4	921	307	242	176	307	176	176	180	0.52

Table 4.8: Detailed problem data and results for case-study 4 (Part III)

S. #	Day				Crude				Available Rectification Option (kbbl)			Optimal Rectifications (kbbl)			Safety Stock (kbbl)	$\varepsilon$
	Crude Recd	Detected	Stock- out	Delivery	On Board	Rcd	Parcel rejtd	Rqd	Proc	Sales	Opn	Proc	Sales	Opn		
51	87	90	93	99	1624	974	4	412	274	117	148	274	117	117	360	0.95
52	87	90	93	99	1730	1038	4	419	282	120	164	282	120	120	360	0.96
53	87	89	92	92	1670	1002	4	576	308	171	163	308	163	163	460	0.82
54	66	69	72	78	1634	980	4	325	262	134	188	262	63	63	260	1.00
55	80	83	86	92	1795	1256	3	416	269	129	158	269	129	129	290	0.96
56	59	62	65	71	1634	1144	3	340	264	113	149	264	76	76	130	1.00
57	59	62	65	71	1639	1148	3	368	291	112	165	291	77	77	170	1.00

#### 4.6 Case-study 5: Facility Operation Disruption

In this case study we consider the scenario where operations problems with any facility can lead to disruption. The modeled refinery procures the crude, processes it, and at end of the day, it measures production. The products are distributed into products on the basis of straight run according to the cuts of the crude. We consider a scenario, where due to certain technical problem the CDU starts running inefficiently and the production is affected. The monitoring agent evaluates the efficiency of production everyday, on the basis of data received from production and operations agent as follows:

$$P_{cp} = CC_{cp} \times TP_n$$

$$\Delta P_p = P_{cp} - P_{np}$$

$$\eta = \sum_p \frac{\Delta P_p}{P_{cp}}$$

where,

$\eta$  is efficiency of CDU

$p$  is number of products

$\Delta P_p$  is difference of expected production from actual production for product p

$P_{np}$  is the actual production of product p from for day n

$P_{cp}$  is the theoretical production of product p from crude c

$CC_{cp}$  is crude cut of prduct p from crude c

$TP_n$  is throughput for day n

If efficiency goes lower than the stipulated lowest allowable efficiency then disruption is detected and information is passed on the root cause diagnosis agent. Upon getting information about the functions of other agents in refinery supply chain it concludes that the disruption is due to malfunction of production facility in refinery supply chain. The rectification seeker agent then estimates the loss of production due to this fault. And then it seeks rectification option from refinery agents, then optimal strategy seeker agent optimizes it and corrective actions are implemented to supply chain.

We apply our disruption management system on this disruption and present the results in Table 4.9. Description of run no 1 is given as follows:

Run1: The monitoring agents detects that the CDU is running inefficient. The information is sent to the Disruption Diagnostic Agent and it confirms on day 60 that the CDU has been running inefficient since day 56. It gives information to rectification options seeking agent, which evaluates that the loss of production can be recovered by 242 kbbl of extra processing of crude. Since the volume of extra crude required is not very high, it can be adjusted within the safety stock level. So, no emergency crude procurement was required in this case. After the CDU is fixed, the operation requires to change its throughput and to recover for the production loss. Since, there has not been enough production for demand delivery; sales department needs to postpone the delivery according to the production. So rectification options are sought from there two agents. Sales agent proposes 347 kbbl and operation proposes 115 kbbl. The optimal rectification is 115 kbbl and the resilience index achieved is 0.48.

Table 4.9: Detailed problem data and results for case-study 5

S. #	Day		Production loss (kbbl)	Recovery options available		Optimal options		$\epsilon$
	occurred	detected		Sales (kbbl)	Opn (kbbl)	Sales (kbbl)	Opn (kbbl)	
1	56	60	242	347	115	115	115	0.48
2	90	93	112	115	121	112	112	1.00
3	64	67	180	237	193	180	180	1.00
4	53	58	485	312	634	312	312	0.64
5	58	62	249	142	339	249	249	1.00
6	84	88	159	196	220	159	159	1.00
7	73	77	249	366	250	249	249	1.00
8	94	98	270	310	153	153	153	0.57
9	61	66	439	404	328	328	328	0.75
10	57	61	267	385	197	197	197	0.74

## **Chapter 5 Conclusion and Recommendations**

The competition of today's business environment is compelling managements to adopt new trends in the business. These trends are adding complexity to supply chain networks and are weakening the visibility in supply chain from one end to another. Hence, supply chains are becoming more vulnerable to disruptions and monitoring and controlling of disruptions is needed. In this work, an integrated and generic framework has been presented for handling various disruptions in supply chains. This framework is built on modular architecture and incorporates steps like monitoring of supply chain, detecting disruptions, diagnosing root cause, finding rectification options, optimizing the rectification options and implementing the corrective actions. This framework is then implemented in refinery supply chain using Disruption Management System (DMS). Feedforward and feedback control methods for capturing disruptions are discussed in this work.

Supply chains and disruption management system (DMS) are efficiently modeled using multi-agent system. A key advantage of the proposed approach is that the disruption management agents handle various classes of disruptions by following a general purpose methodology independent of the functionalities of the supply chain entities. Like a feedback controller in process control, it thus is suitable for a variety of scenarios -not all of which may have been foreseen. The system has been successfully tested on a simulated refinery application. From the several case-studies presented, it can be concluded that both methodologies are equally necessary for dealing with all disruptions in supply chain. The case studies presented are adequate to illustrate the versatility of application of DMS. This system can be used for determining the

parameters of supply chain, like inventory levels, procurement cycle frequency, safety stock level etc.

In this work, methodologies for selection of crude basket for procurement are imbedded in G2. Future work may be to accommodate crude scheduling processing in the framework. This activity can be performed using an optimization software such as GAMS, ILOG etc. and the results can be plugged into the supply chain simulator. DMS can interface a program (Adhitya (2005)) to retrieve accurate rectification options for managing disruptions. In this work, the optimization of the rectification options is based on priority levels, and rigorous optimization is not used. In future work, the rectification options can be optimized based on the cost of rectifications and this optimization exercise can be performed on optimization software and the results can be used by the DMS.

In this work, a decision support system for disruption management was presented. In future, this system can be used for robust design of supply chain also, by selecting different scenarios and parameters of supply chain simulator. For example, if the suppliers are providing lower quality of crudes quite frequently and this leads to frequent disruptions, using this system, the optimal safety stock level can be estimated and supply chain can be ensured for undisrupted process. The system can be modified and similar case-studies can be used for rating suppliers for their quality of goods. Design of supply chain networks for disruptive environment can one of the future works. In disruptive atmosphere, the supply chain may require different supply chain networks than usual. The business policies must also be studied for disruptive scenarios. Flexible production policies may be required for handling frequent changeovers in demands. In this work, the

application of framework is focused on refinery supply chains, but this framework is still required to be tested on other supply chains.



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